1962

A synoptic study of the January 1962 Monterey snow.

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Monterey, California. Naval Postgraduate School

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THESIS

A SYNOPTIC STUDY OF THE JANUARY 1962 MONTEREY SNOW

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By

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Lieutenant, Japanese Maritime Self Defense Force

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
METEOROLOGY

United States Naval Postgraduate School
Monterey, California

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This work is accepted as fulfilling

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from the

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[redacted]

Chairman, Department of
Meteorology and Oceanography

Approved:

Academic Dean

ABSTRACT

A synoptic study of the January 1962 snow at Monterey is made. Attempts are made to find synoptic features and critical temperatures which may be considered to be favorable to snow at Monterey, California.

Some comparisons of past snow situations to the 1962 snow are also studied and it is shown that air trajectories and an upper flow pattern which situates an intense blocking high over Alaska and a cut-off low in the vicinity of Monterey play the most important roles for the snow at Monterey.

An 850-mb temperature between -5C and -6C appears to be the critical temperature for snow at Monterey.

The writer is deeply indebted to Professor W. D. Duthie, the chairman of the Department of Meteorology and Oceanography at United States Naval Postgraduate School for advice and guidance in the preparation of this study.

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TABLE OF SYMBOLS AND ABBREVIATIONS

F.N.W.F.	Fleet Numerical Weather Facility
GMT	Greenwich Mean Time
gpft	geopotential feet
N.A.F.	Naval Air Facility
P	pressure
PST	Pacific Standard Time
θ_e	Equivalent potential temperature
S	Snow
SP	Snow pellet
SW	Snow shower
t	time
#	U. S. Weather Bureau, Northern Hemisphere Series
*	U. S. Weather Bureau, Facsimile analysis

1. Introduction

Studies of forecasting of snow vs. rain have been made by many investigators. Some for the Unites States are summarized in U. S. Weather Bureau Forecasting Guide No. 2, The Prediction of Snow vs. Rain [1]. However no methods have been given for snow prediction in Southern California.

This study is a postmortem of the synoptic situation associated with the January 1962 California snow, in an attempt to show if and how it might have been forecasted.

2. The synoptic features

2-1 Specific features of large scale pattern

Fig. 1 shows the 500-mb 5-day (19 to 23 Jan. 1962) mean contour chart. It may be noticed that there had been a deep long-wave trough in the vicinity of 135E, an intense ridge near 145W which had a closed low at about 45N 170W, and a sharp trough oriented NE-SW passing over Monterey.

The strong ridge along 145W acted as a block during this period. The main roles of this block were: (1) establishment of N-to-S oriented flow pattern along the U. S. Pacific Coast which transported Canadian cold polar air to the south; (2) production of a cold-core low (as shown later); and (3) deformation of the jet stream which steered the cold low further south.

2-2 Movement of fronts and air masses

In the sequence of surface maps of fig. 2, it may be seen that: (1) at 170000Z, the arctic front was nearly in its usual position; (2) at 180000Z, the arctic front moved S-ward over the Middle West and the low at 40N 152W was occluded and meeting with a cold outbreak from Canada; (3) at 190000Z, the arctic front continued to move S-ward over the Middle West and the cold front from the Pacific moved into Oregon and Northern California; (4) at 200000Z, the arctic front reached its southernmost position and the cold front from the Pacific continued to move SE-ward; and (5) by 210000Z, the arctic front had been overtaken by the cold front from the Pacific and from then until 220000Z, the western part of the connected frontal system continued to move SE-ward while, the eastern part of the front moved northward. In fig. 3, the consecutive positions of the fronts are shown.

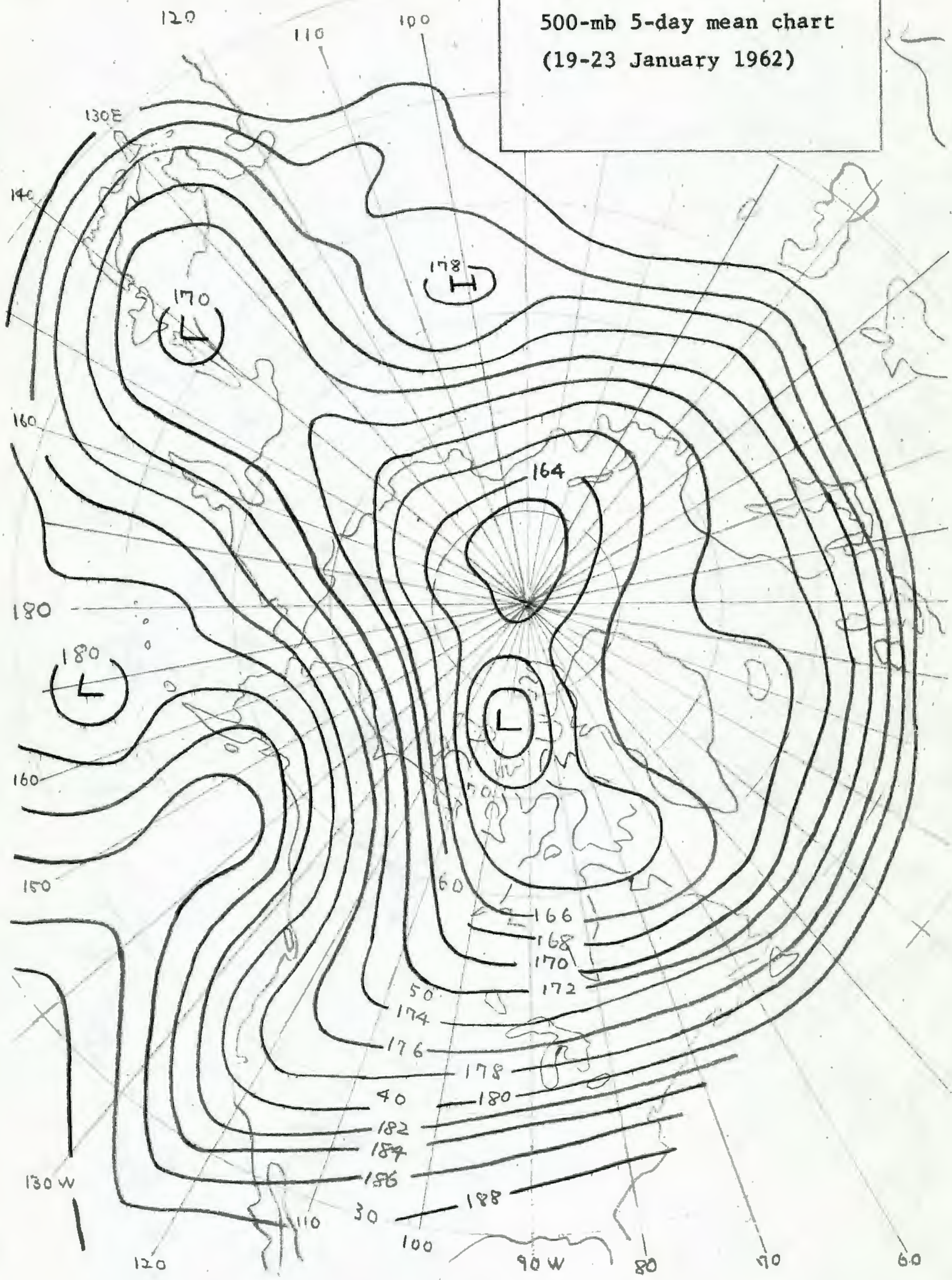


Fig. 1
500-mb 5-day mean chart
(19-23 January 1962)

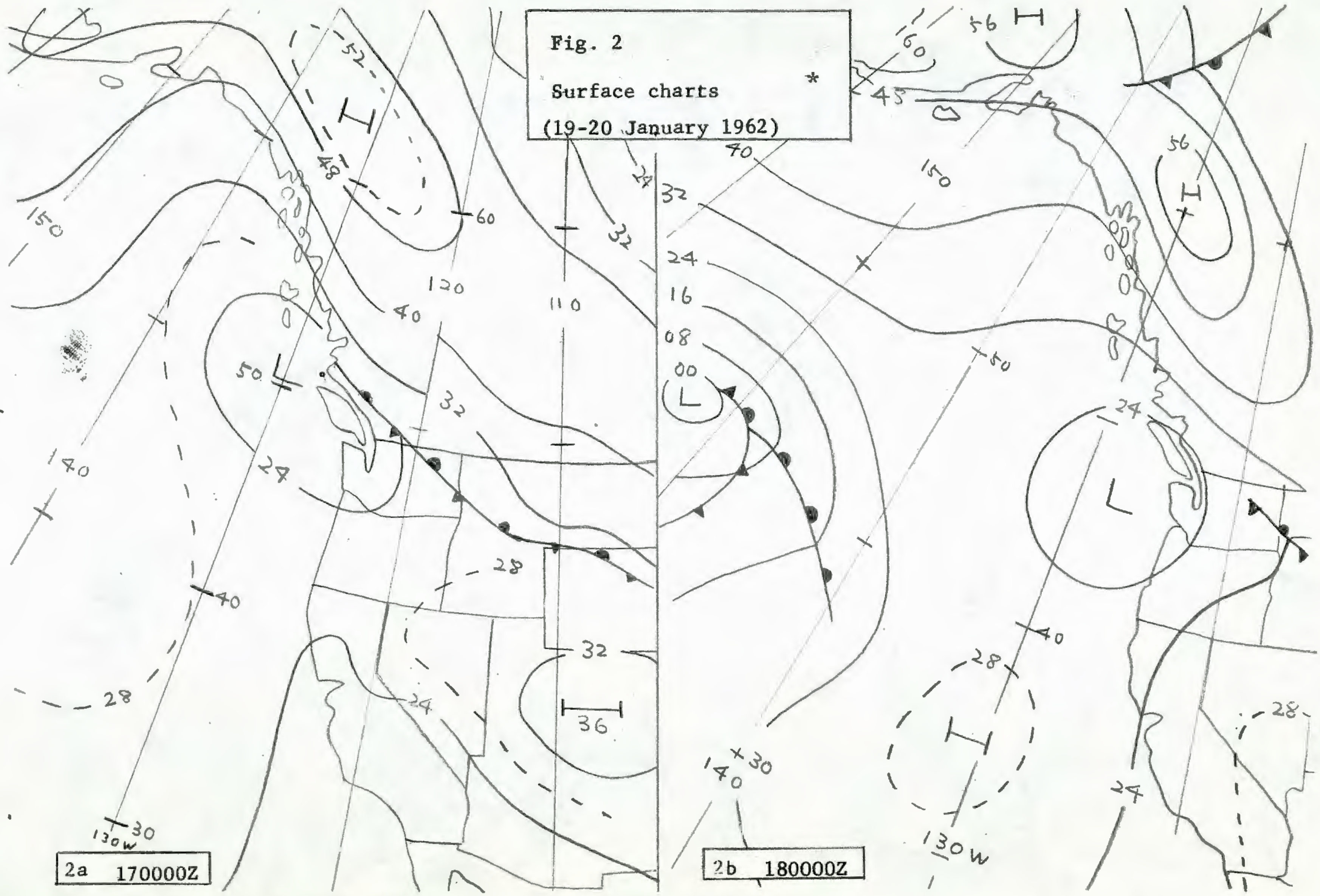


Fig. 2

Surface charts *

(19-20 January 1962)

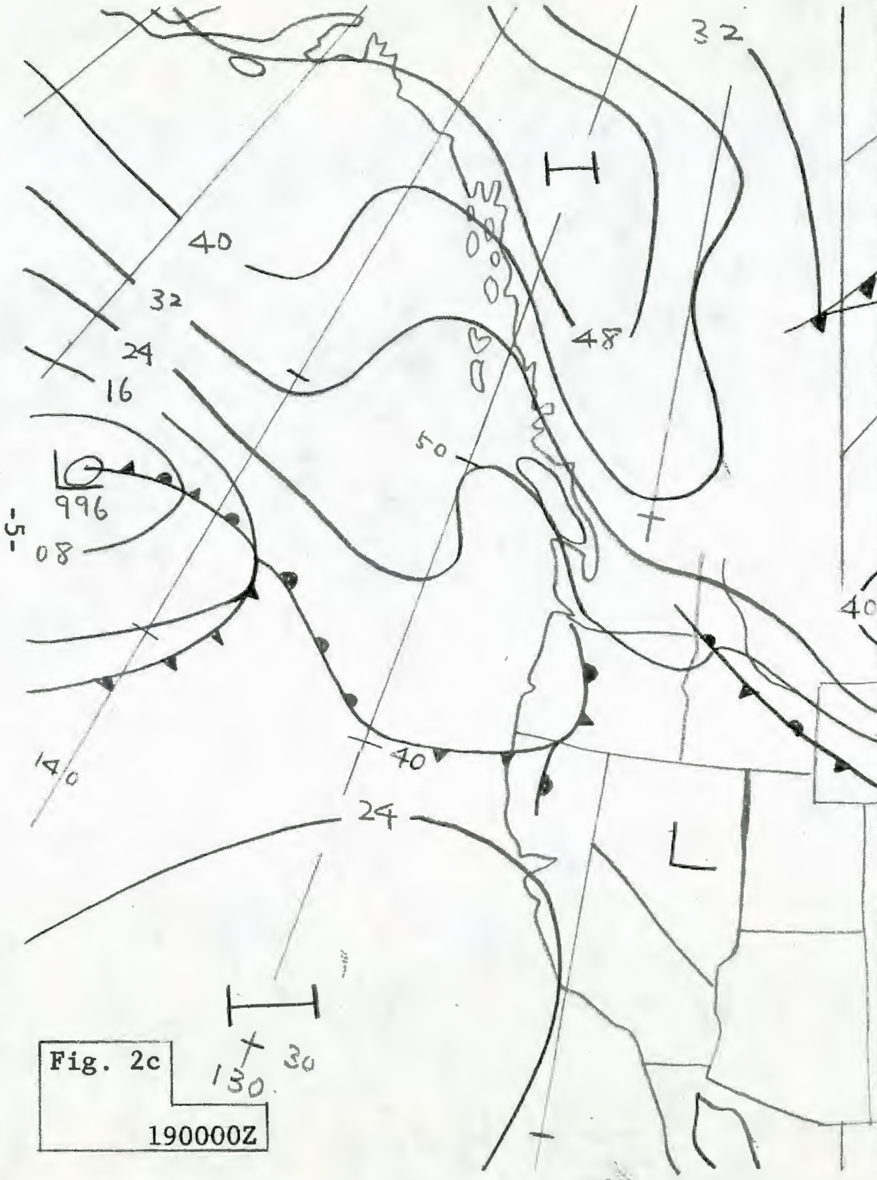


Fig. 2c 190000Z

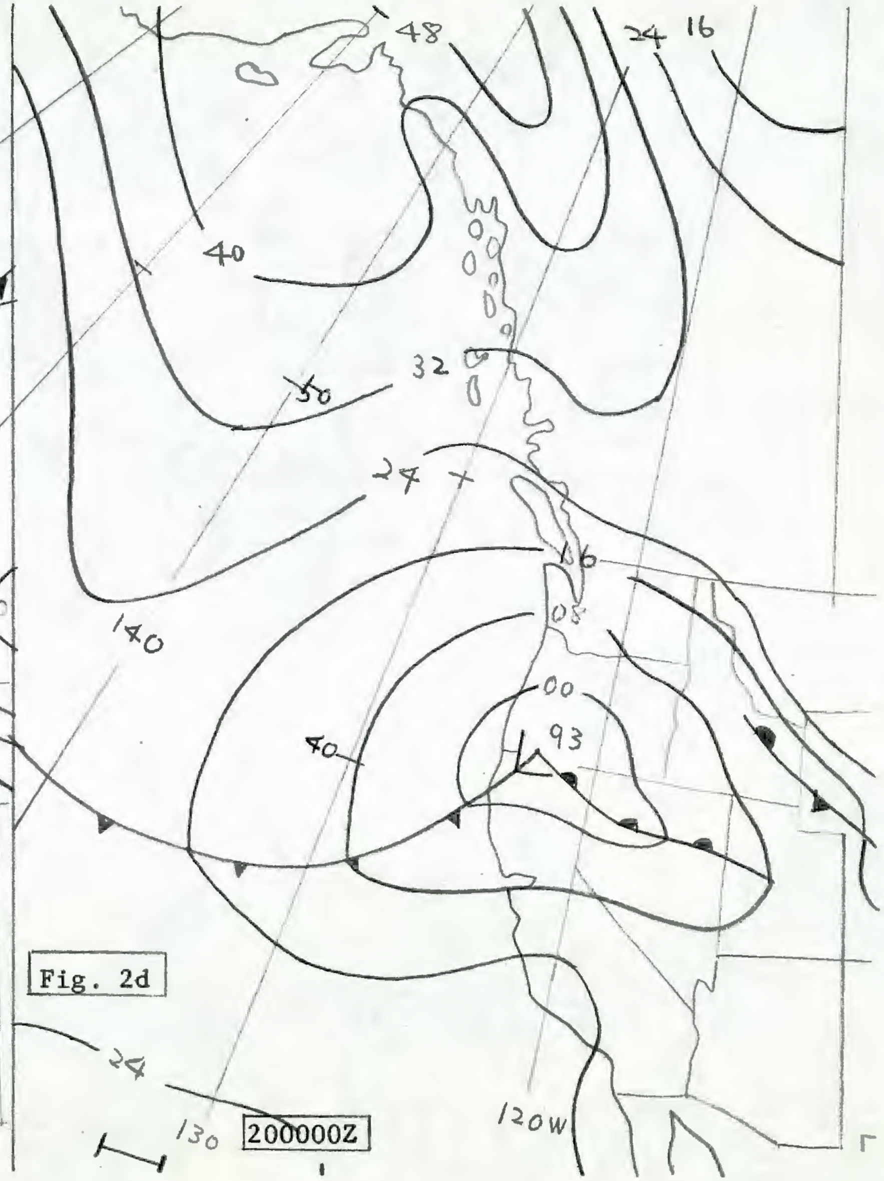


Fig. 2d 200000Z

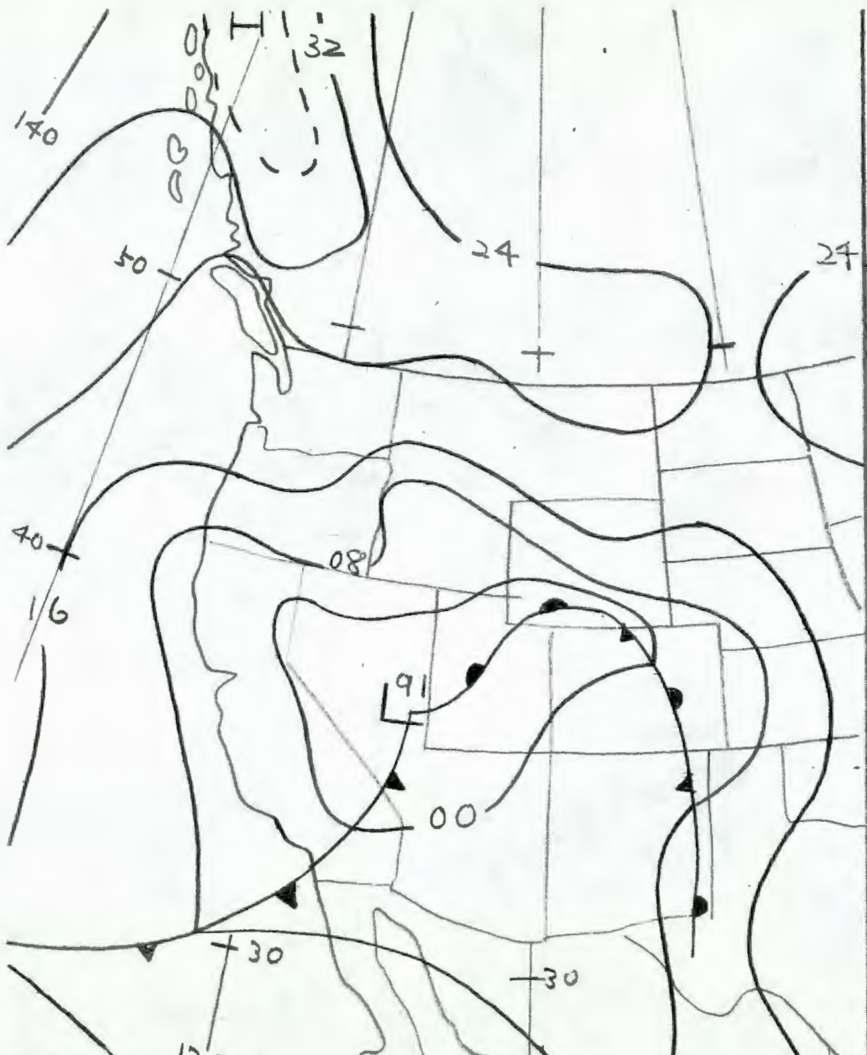


Fig. 2e 210000Z

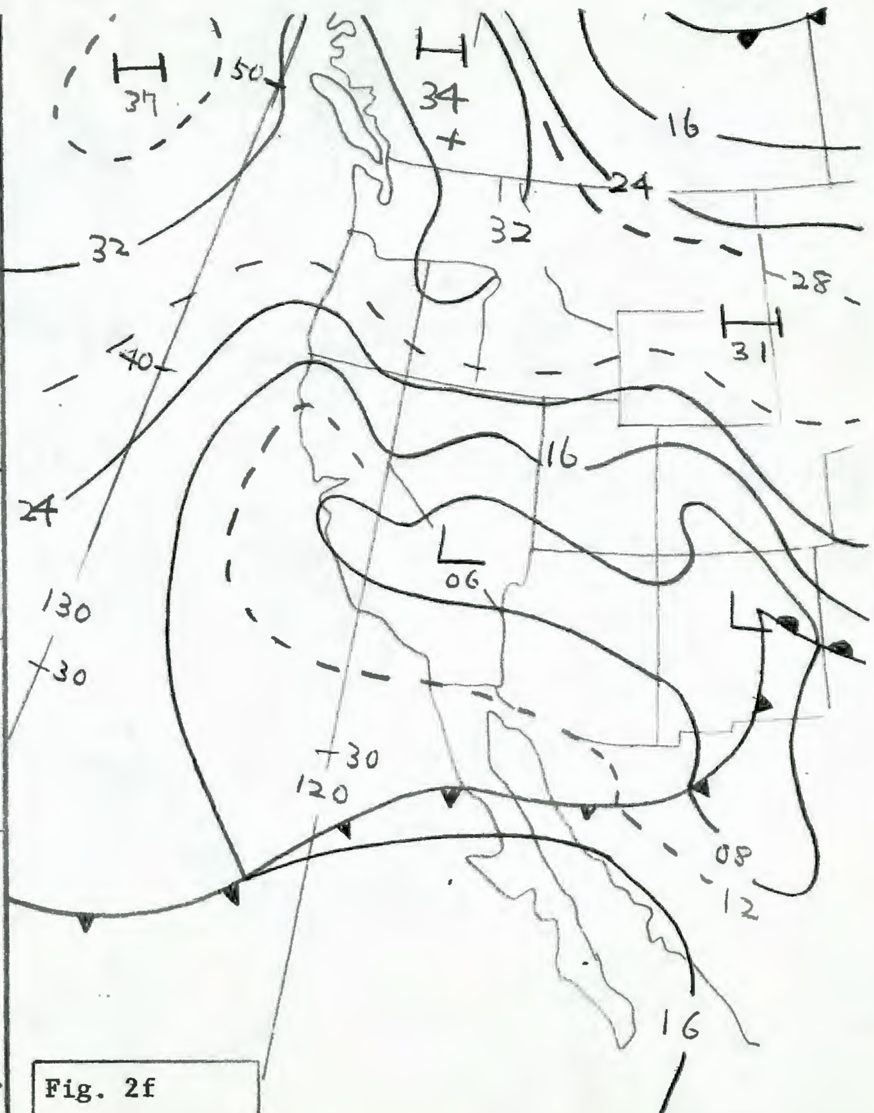


Fig. 2f 220000Z

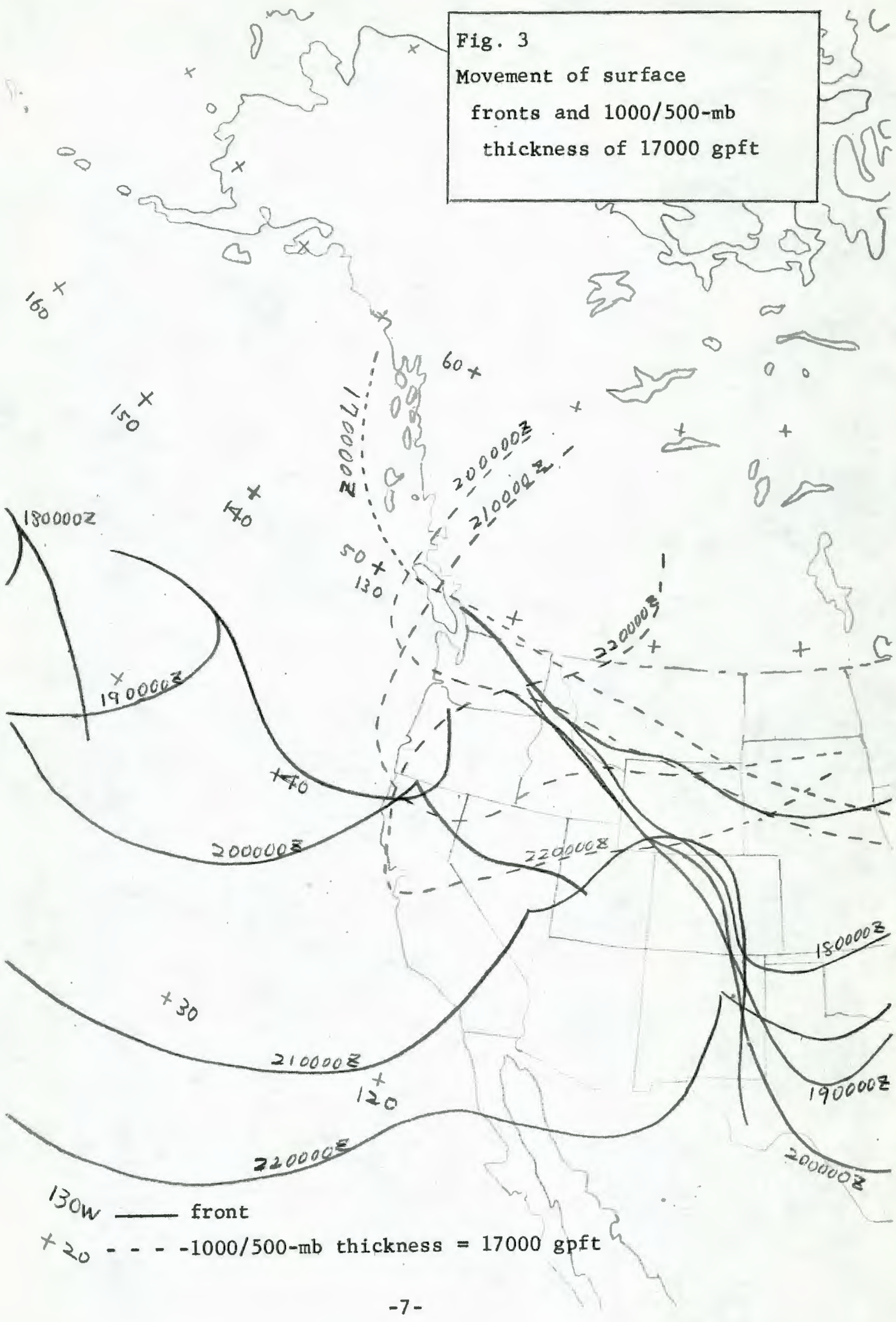


Fig. 3
Movement of surface fronts and 1000/500-mb thickness of 17000 gpft

—— front

- - - -1000/500-mb thickness = 17000 gpft

As a summary, it may be said that at first the arctic front began to move S-ward in its eastern portion with gradual change to polar-front properties; next the cold front from the Pacific moved onto the coast and at the same time a cold outbreak began along the northwest coast of United States which pushed this front further south with accompanying cold temperatures.

From the above considerations, it may be said that the air mass which invaded southern California was not mP air in the usual sense but cP or cA air from Canada.

2-3 Air trajectories

Fig. 4 shows the surface trajectory of an air parcel which arrived at Monterey at 211800Z. For the calculation of the trajectory, 6-hourly surface charts provided by Fleet Numerical Weather Facility, Monterey, were used. For checking, especially for the segment crossing the Rocky Mountains, the isentropic chart corresponding to a constant potential temperature of 265.5 A was used. For the calculation of surface air trajectories the following equation was used:

$$\frac{1}{r_t} = \frac{1}{r_i}\left(1 - \frac{c}{v}\cos\psi\right)$$

where r_t is the radius of curvature of air trajectory, r_i is the radius of curvature of isobars, c is the speed of the systems, v is the wind speed (speed of parcel), and ψ is angle between the wind and the direction of movement of the system. A cross-isobar angle of 30 degrees was assumed.

Choice of 265.5A as a constant potential temperature was determined by the fact that an 850-mb temperature of -5C (which is nearly equal to a potential temperature of 265.5A) seems to be favorable for snow in the several past snow situations at Monterey, as shown in a later section.

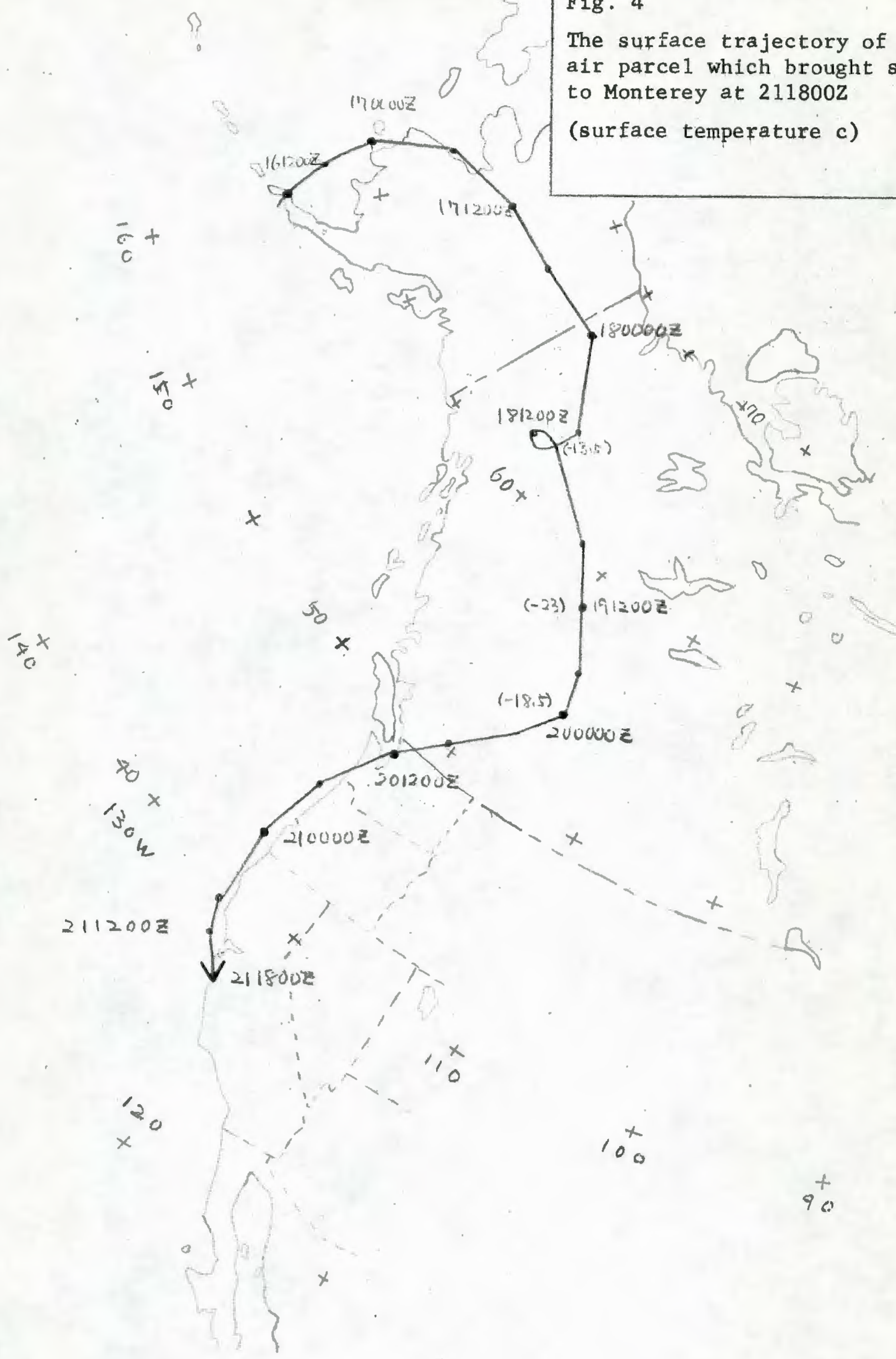


Fig. 4

The surface trajectory of an air parcel which brought snow to Monterey at 211800Z

(surface temperature c)

In fig. 5, the equivalent potential temperature (θ_e) cross sections are shown. The stations used in the cross sections were chosen as the nearest radiosonde stations to the trajectory shown in fig. 4.

Following the 275A θ_e surface (assuming that θ_e was conservative during this period), it may be seen that:

(1) until 190000Z the air whose θ_e=275A gradually piled up east of the Rockies; (2) before 200000Z the air began to cross the Rockies from east to west; and (3) it finally arrived near Oakland, California (493) at 220000Z with low-level convective instability.

This is seen also in fig. 4, which shows that the cold dry air would pick up moisture from sea surface after leaving the Washington Coast, before arriving at the California Coast. This is confirmed in fig. 6, which shows the very dry sounding over Seattle (793) at 201200Z and more humid, convectively unstable sounding over Oakland at 220000Z. For comparison, seasonal mean soundings of mP over Seattle and cA over Lakehurst in winter [5, pp. 511] are also shown in fig. 6.

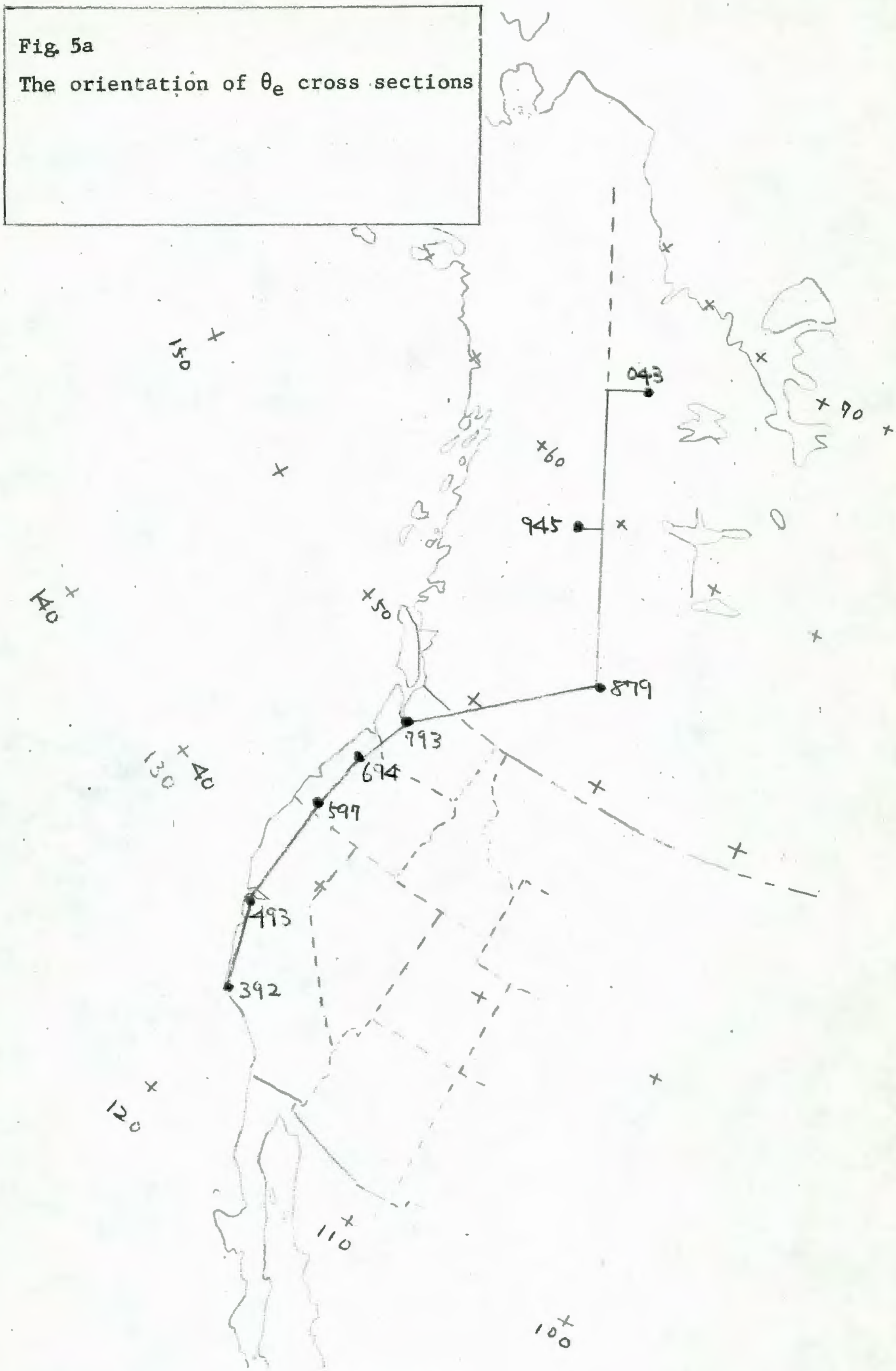
2.4 Description of the cold outbreak

The cold outbreak may be traced by the movement of a 1000/500-mb thickness line. For example, the 17000 gpft (mean virtual temperature is equal to -18C) line was located just north of the arctic front at 170000Z and commenced significant S-ward movement of its western portion at 201200Z and reached its southernmost position over Oakland at 220000Z as shown in fig. 3.

In the sequence of consecutive 500-mb charts of fig. 7 the formation of an upper low over Oregon at 201200Z and its S-ward movement to Southern California may be seen. It may also be noticed that the development of and movement of this upper-level low were associated with the movement

Fig. 5a

The orientation of θ_e cross sections



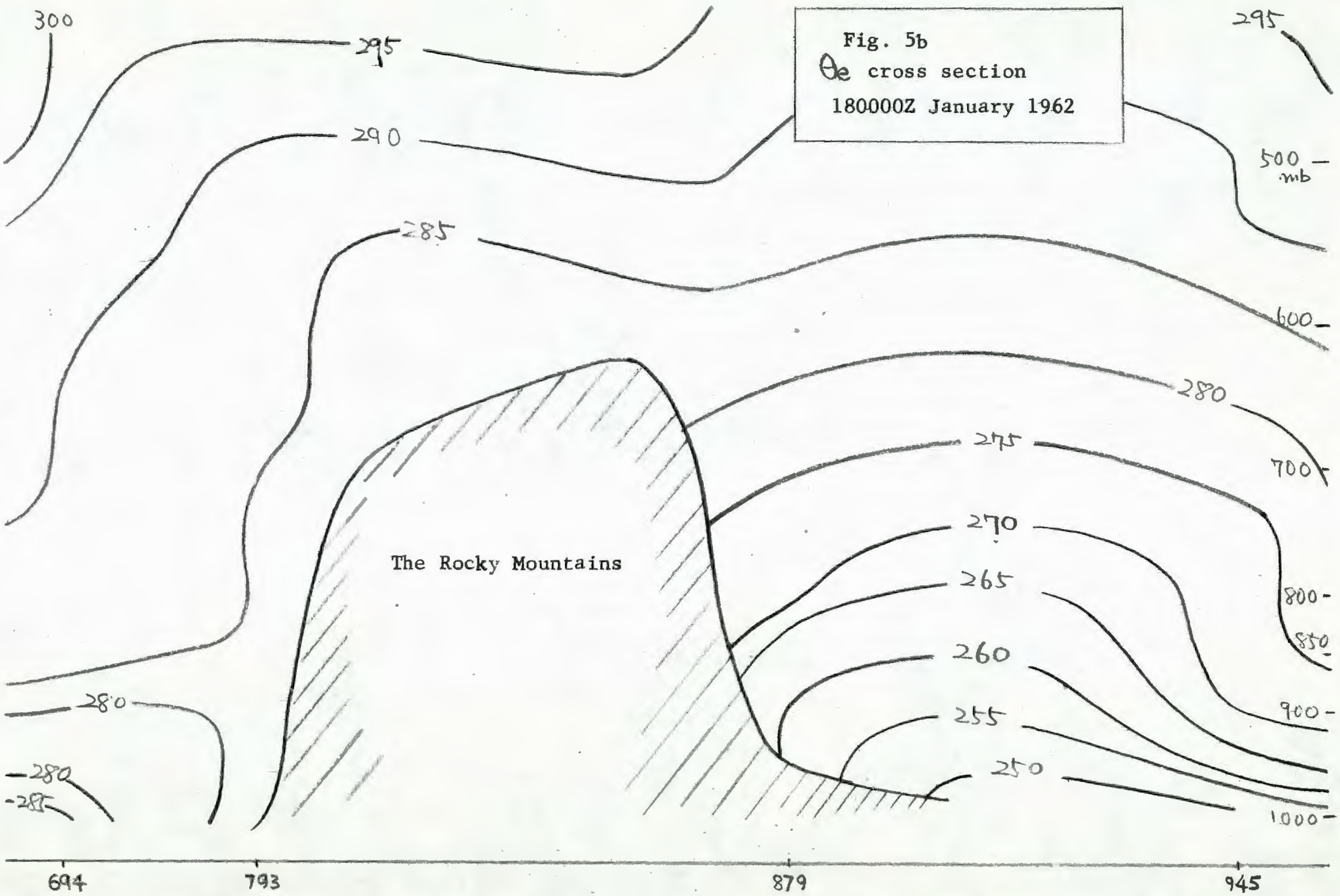


Fig. 5b
θe cross section
180000Z January 1962
The Rocky Mountains
300
295
290
285
280
275
270
265
260
255
250
500 mb
600
700
800
850
900
1000
694
793
879
945

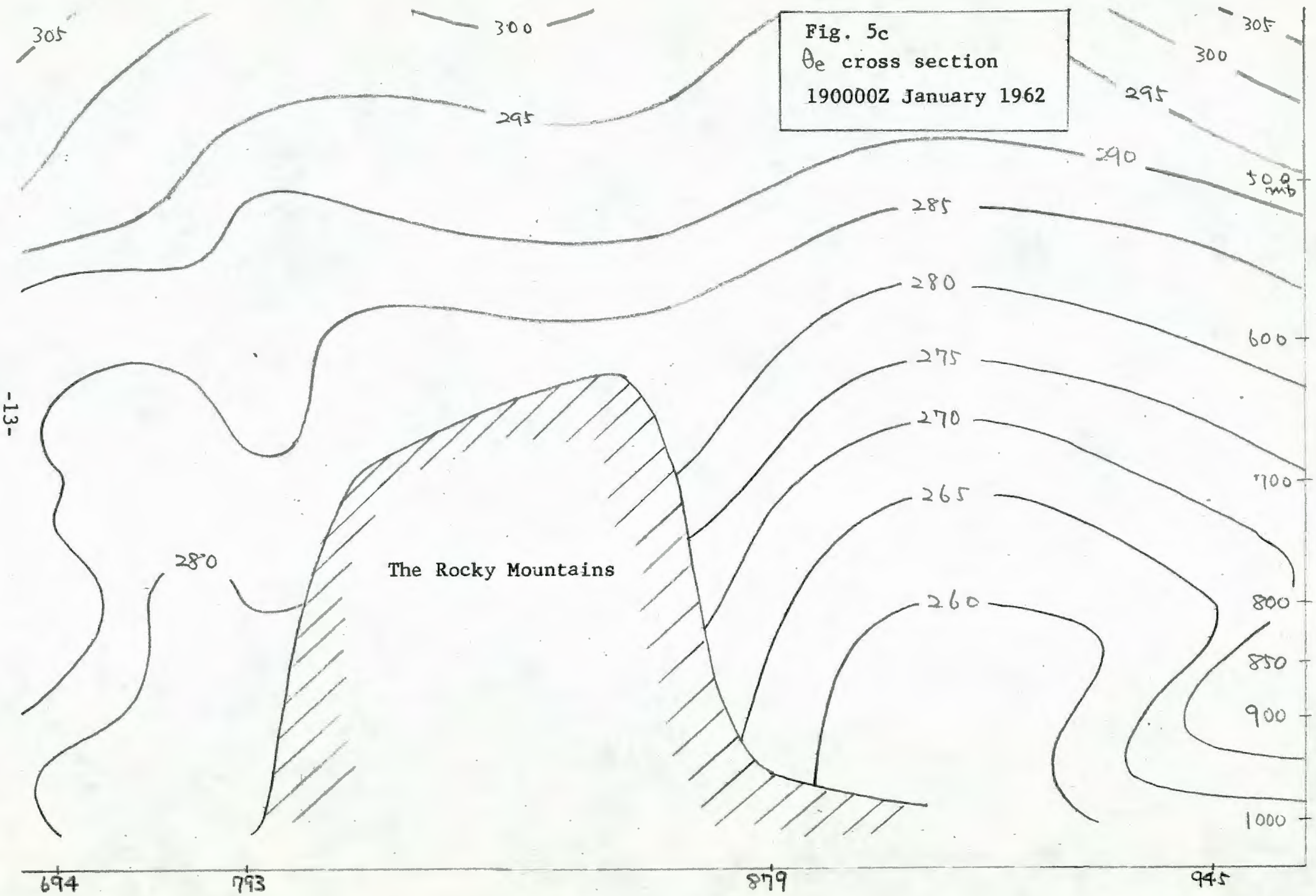


Fig. 5c
θ_e cross section
190000Z January 1962

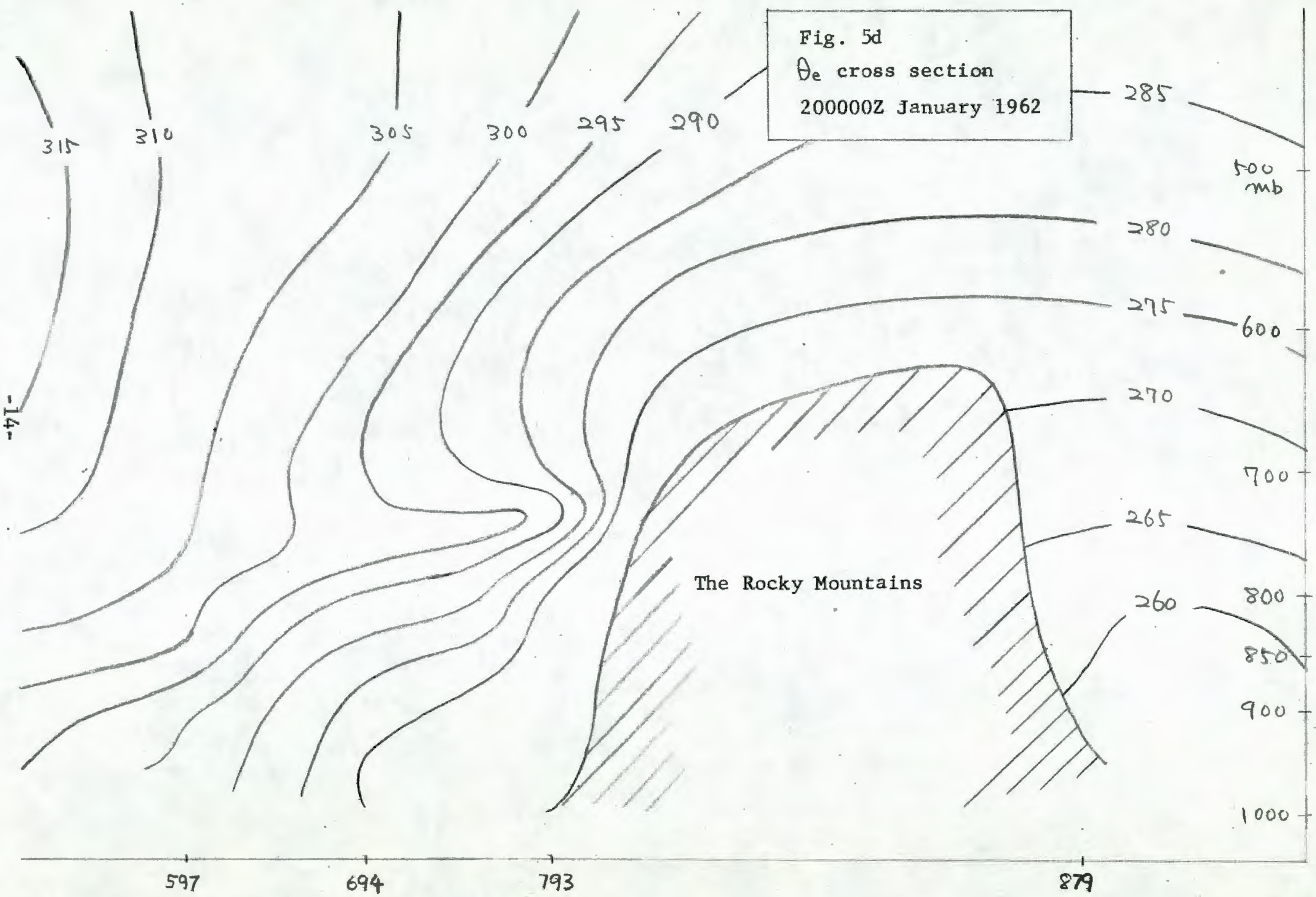


Fig. 5d
θ_e cross section
200000Z January 1962

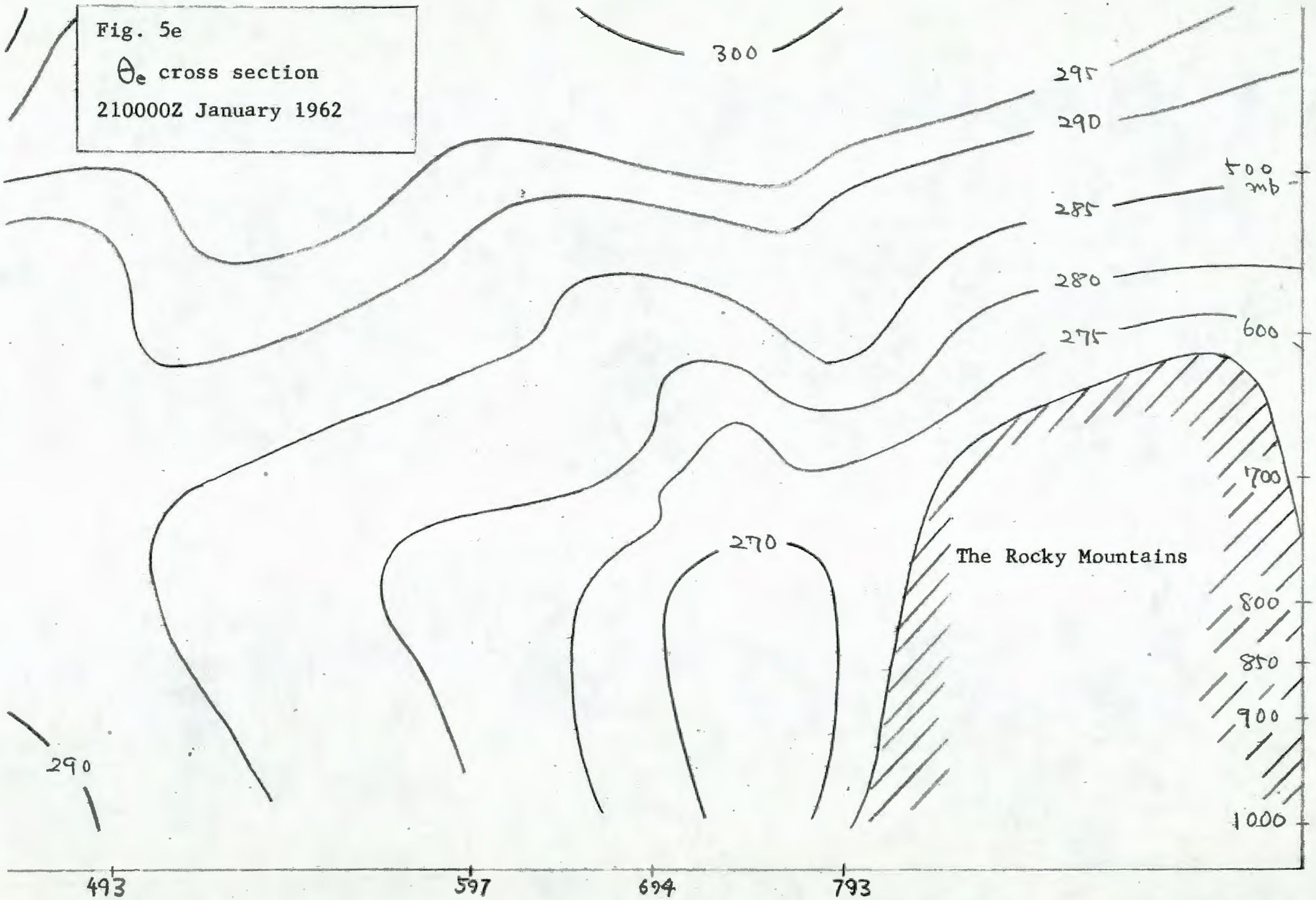


Fig. 5e
θ_e cross section
210000Z January 1962

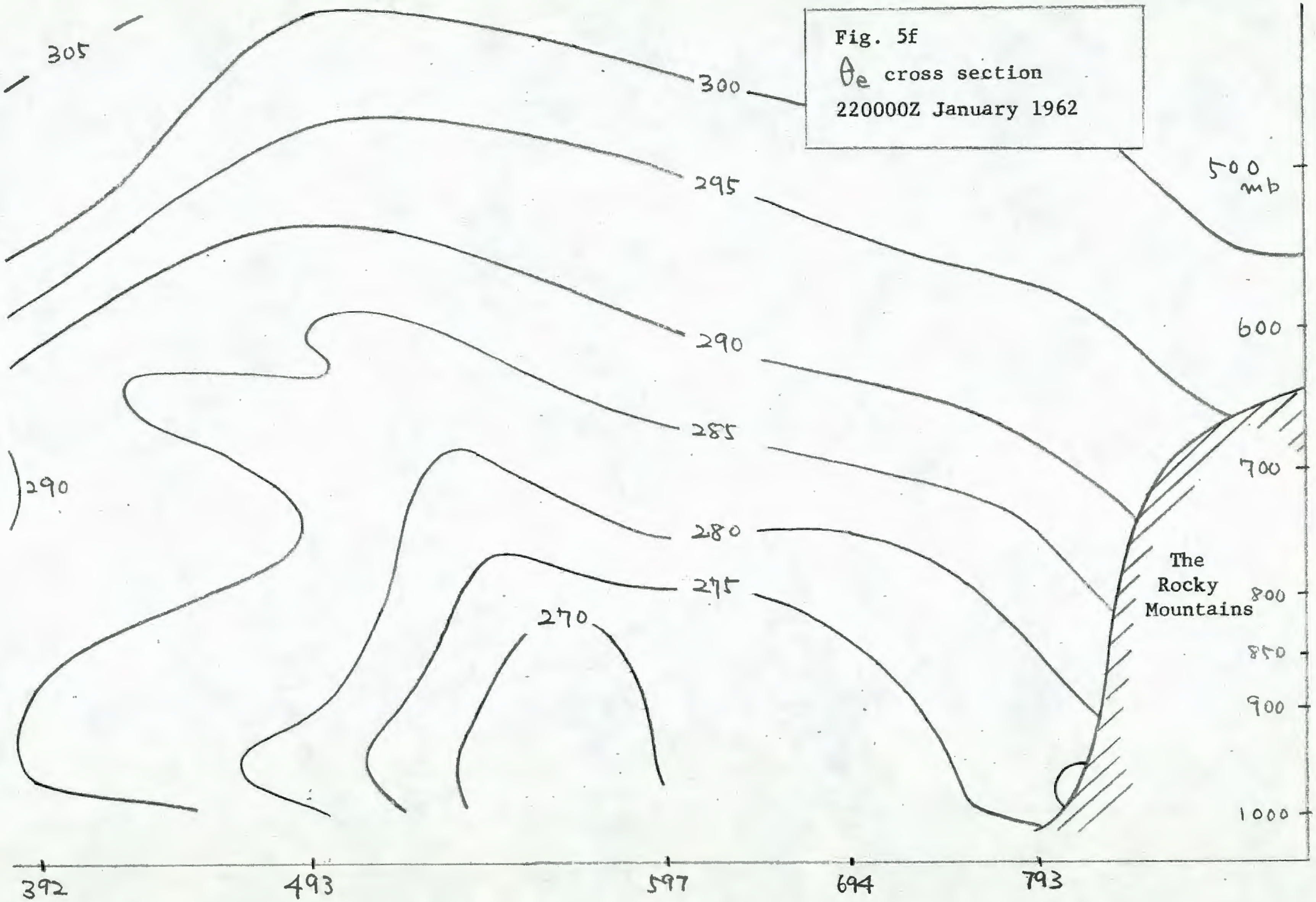


Fig. 5f
θ_e cross section
220000Z January 1962

Fig. 6a

Vertical sounding at Seattle (793)
201200Z January 1962

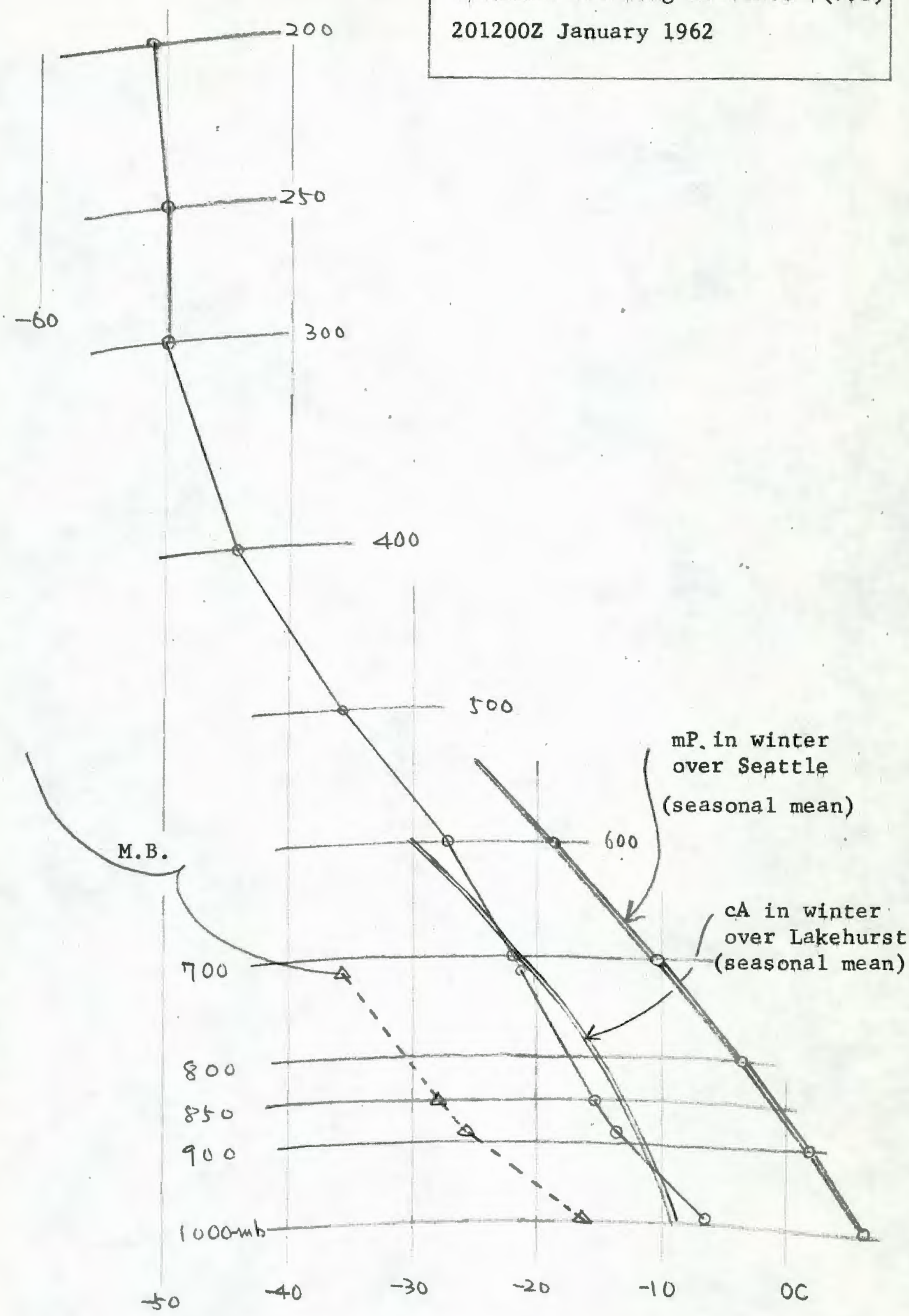
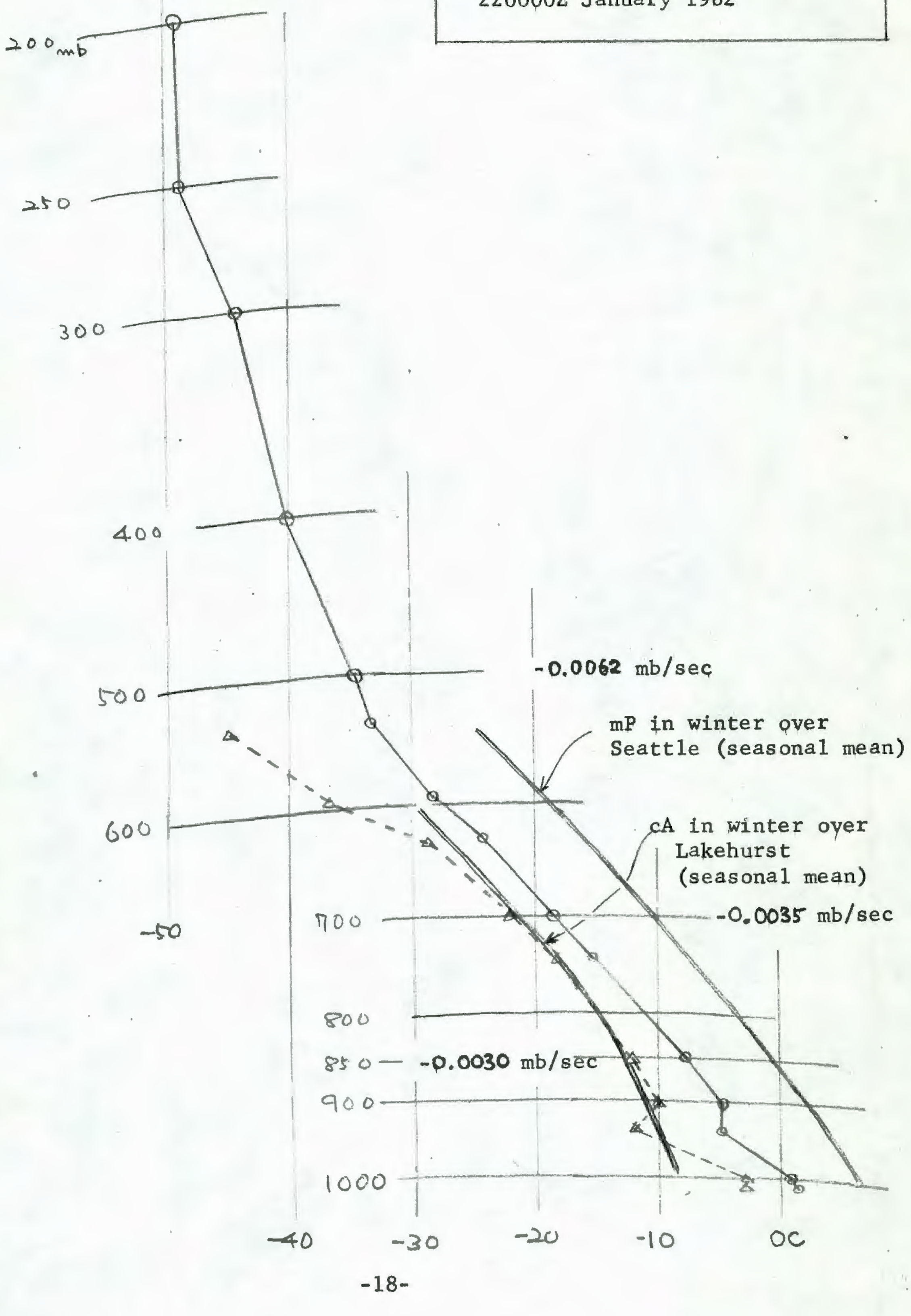


Fig. 6b

Vertical sounding Oakland (493)
220000Z January 1962



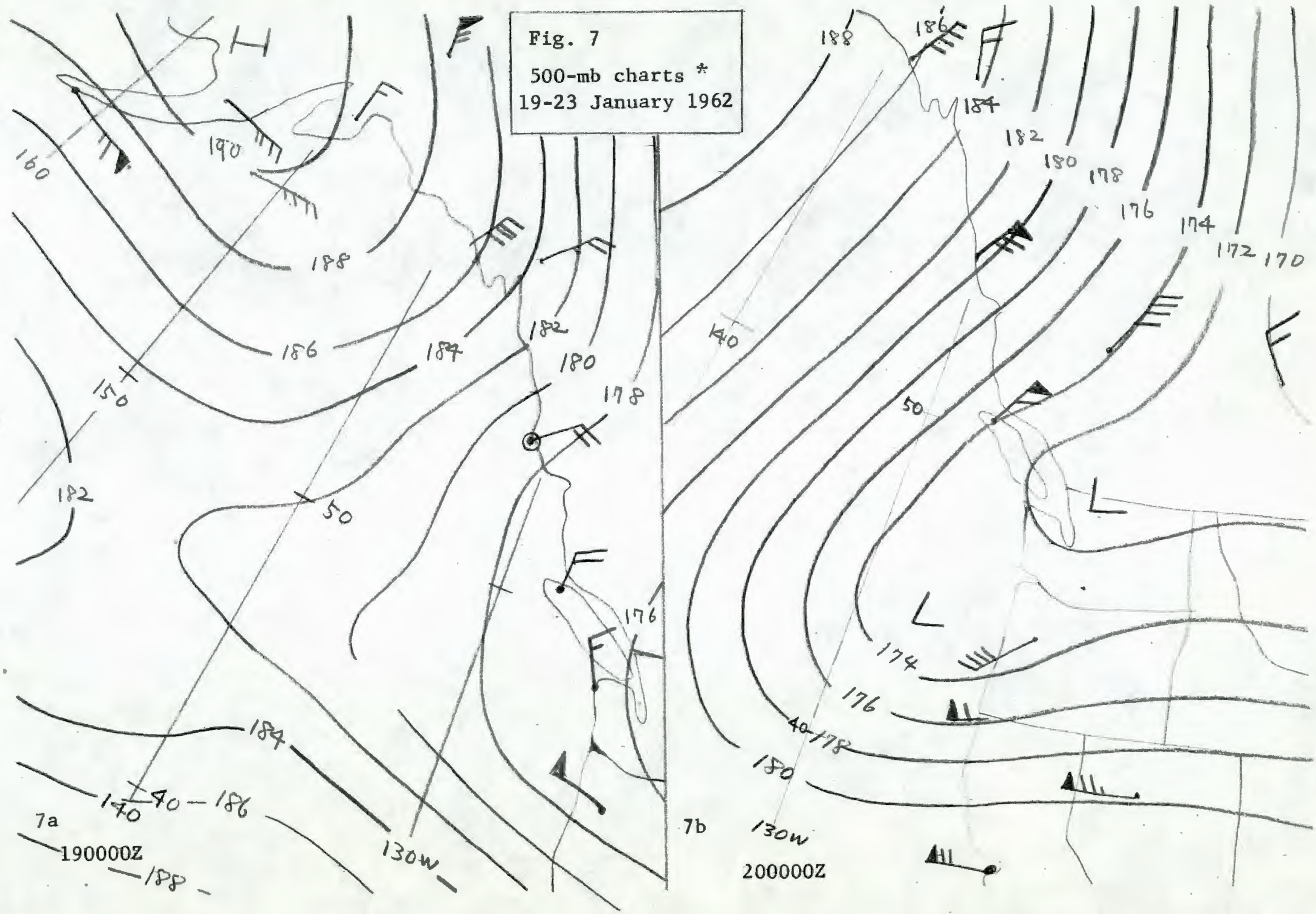


Fig. 7
500-mb charts *
19-23 January 1962

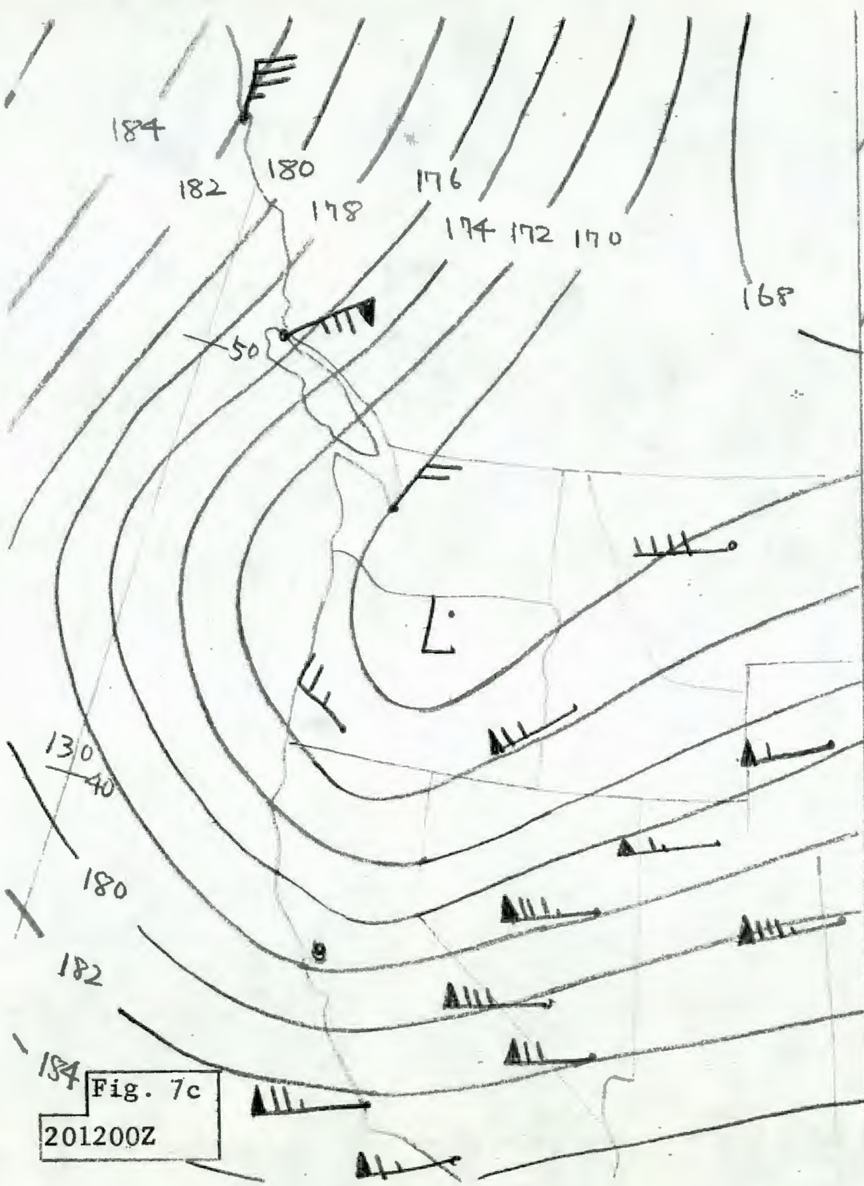


Fig. 7c
201200Z

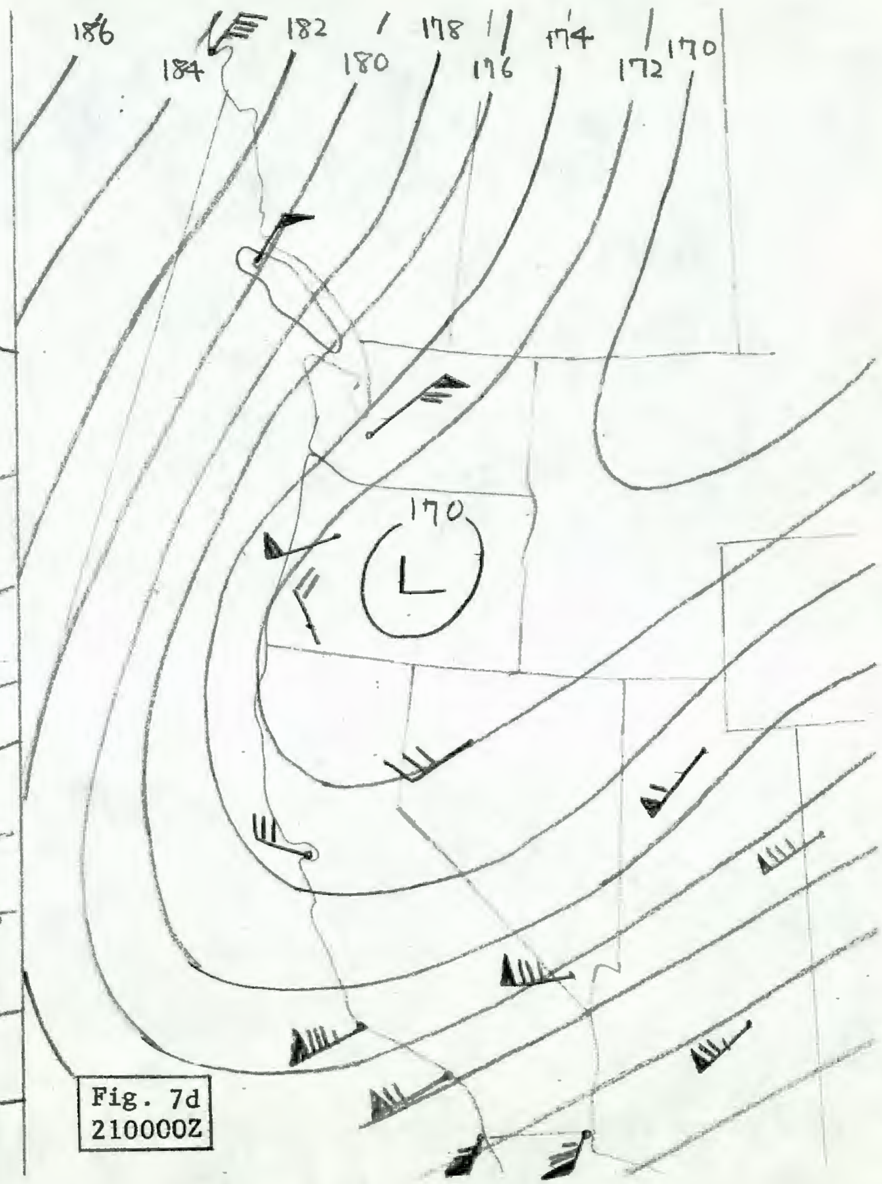


Fig. 7d
210000Z

Fig. 7e
220000Z

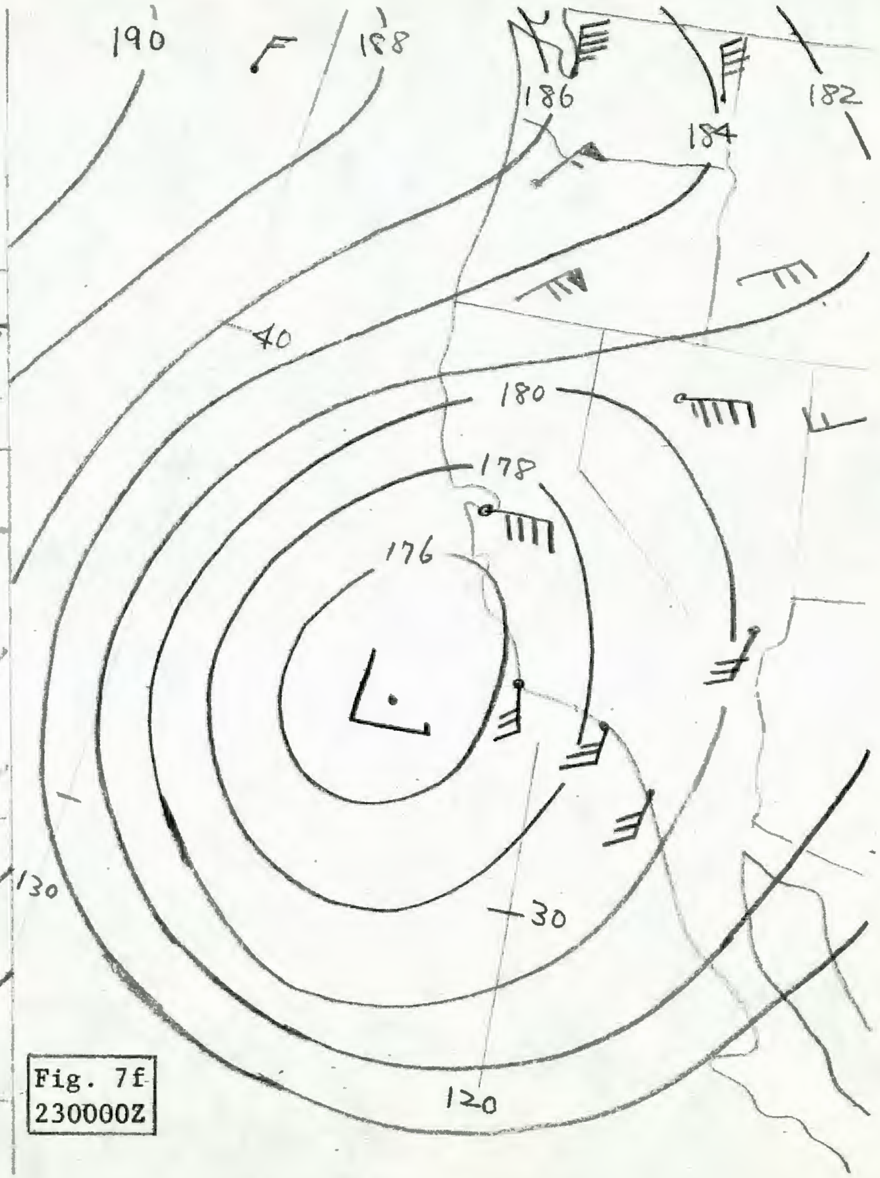


Fig. 7f
230000Z

of the thickness line mentioned and with the cold outbreak.

2-5 Formation and movement of the cold low

In fig. 7, formation and movement of the 500-mb low are shown. An explanation of its formation process follows. In fig. 8, there was a stationary surface low at 33N, 158W at 170000Z, and this low was the reflection of an upper closed low. At 170000Z (chart is not shown here), the surface low has left its original position and become a NE-ward moving wave cyclone, and by 180000Z (fig.2) it has occluded at 40N 132W. At 191200Z it was at 42N, 132W (fig.9), and can be considered as an upper reflection of the surface low in view of the consistency of surface, 850-, 700-, and 500-mb charts.

At 190000Z, the wind at 500 mb at Ketchkan was, 20 kt, at 300-mb it was 50 kt and at 191200Z the 500-mb wind had increased to 85 kt, the 300-mb wind to 125 kt (fig 7 & 10). This sudden increase of wind speed was associated with the isotach maximum of the 300-mb jet stream, and sharpening of the 500-mb trough in the vicinity of Vancouver Island should be expected. At 200000Z, a slight depression (no closed contour) was found at 49N, 121W (fig. 7), while the upper reflection of the surface low was at 44N, 127W, having weakened to a slight depression. It may be considered that these two lows would be rotated counterclockwise by the so-called Fujiwara effect and the former should be weakened by over-shooting [9, pp.81]. At 201200Z, the former's dissipation is shown and existence of the strongest wind at the rear of trough should indicate another intensification of the trough (fig. 7) [9, pp. 86].

At 210000Z, a 500-mb closed low over Oregon is seen and it is no longer a reflection of the surface low which has moved to southeast of Nevada. This low at 500 mb was now established as an upper cold-core low and steered to the south by the jet stream. It played an important role

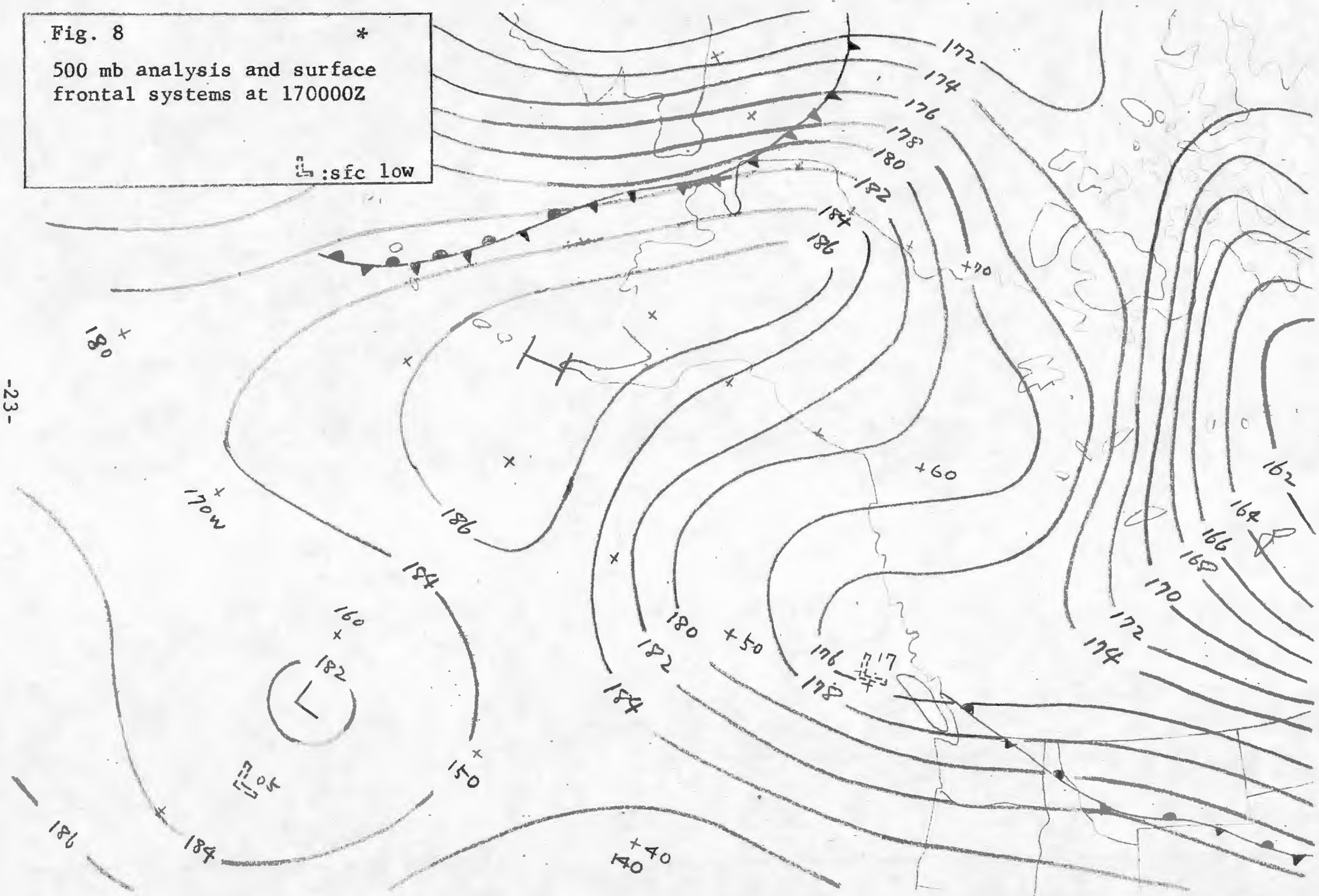


Fig. 8 *

500 mb analysis and surface frontal systems at 170000Z

:sfc low

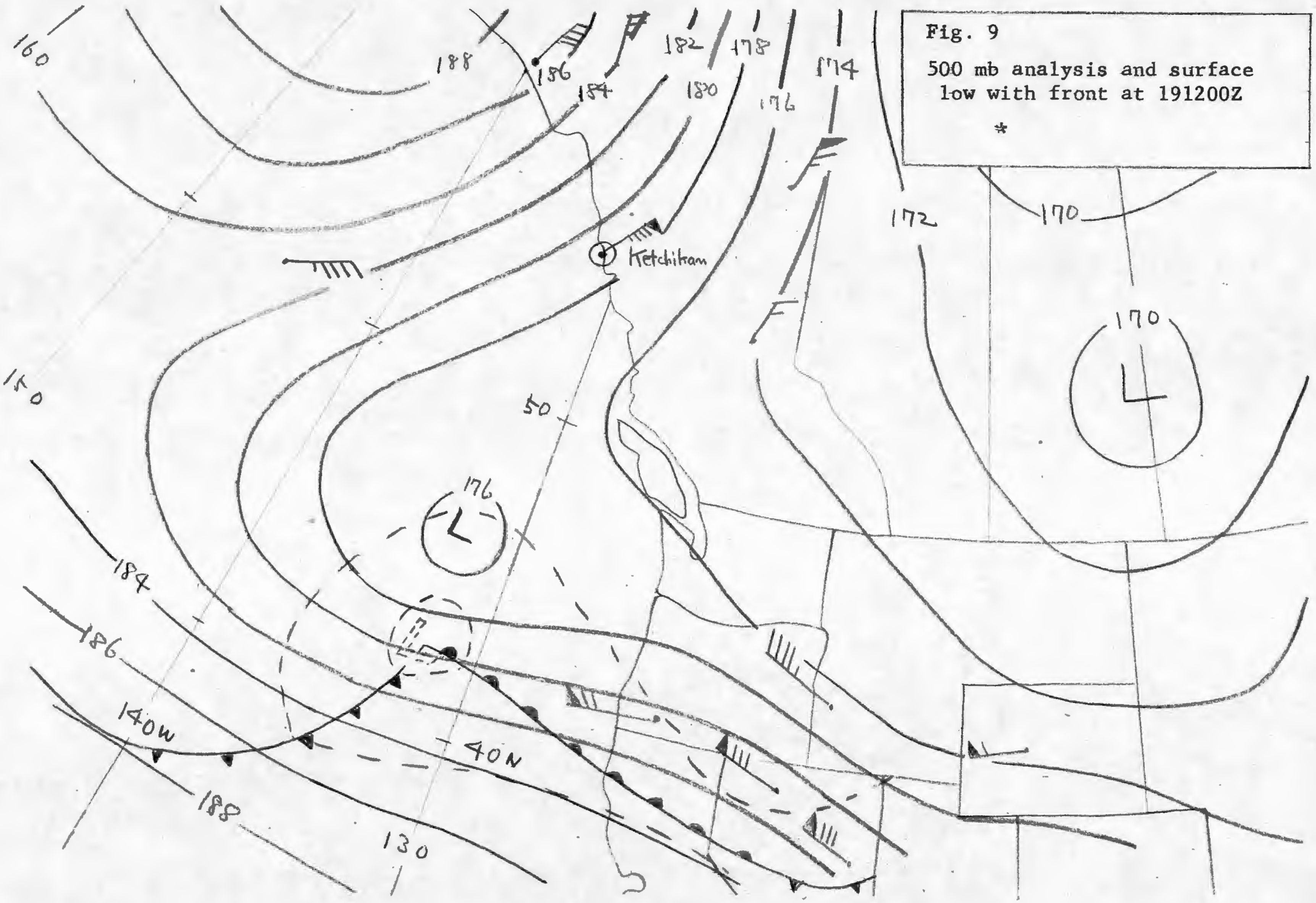


Fig. 9

500 mb analysis and surface low with front at 191200Z

*

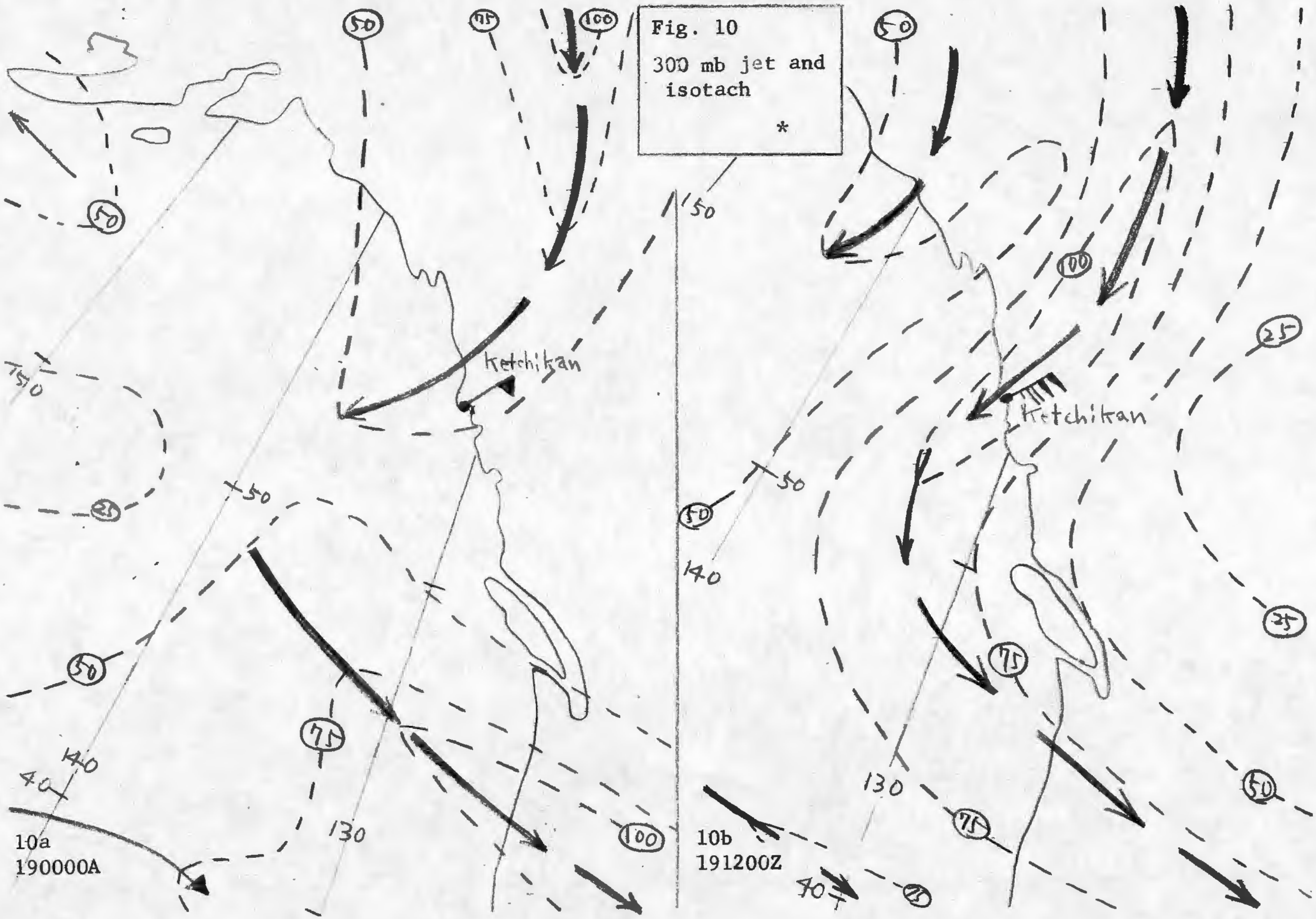


Fig. 10
300 mb jet and isotach
*

in producing the snow over Southern California, as shown in a later section.

As shown in fig. 11, the movement of this 500-mb low was associated with the 300-mb jet stream. Table 1 shows the relation between the 300-mb jet and movement of the 500-mb low.

Table 1

The movement of the 500-mb low and 300-mb jet

Time (GMT)	Movement of the 500-mb low direction	Movement of the 500-mb low speed(1)	300-mb jet direction (toward)	300-mb jet isotach nearest to 500-mb low position (2)	(1)/(2)
210000			205	25 kt	
210000 211200	200	17 kt			0.68
211200			203	25	
211200 220000	199	15			0.6
220000			167	25	
220000 221200	158	15			0.6
221200			189	25	
221200 230000	227	16			0.6

2-6 Snow at N.A.F. Monterey

As shown in fig. 12, the first snow at N.A.F. Monterey, in the form of snow pellets rather than actual snow occurred at 210545PST, and shower-type snow continued almost the whole day of the 21st. During these showers, the surface temperatures were between 39F and 33F, lowering to 32F when actual snow began to fall at 220035PST.

It is known that in most cases snow pellets fall in shower form, with associated convective motion, and this was the case for this snow,

Fig. 11

300-mb jet
and
500-mb low

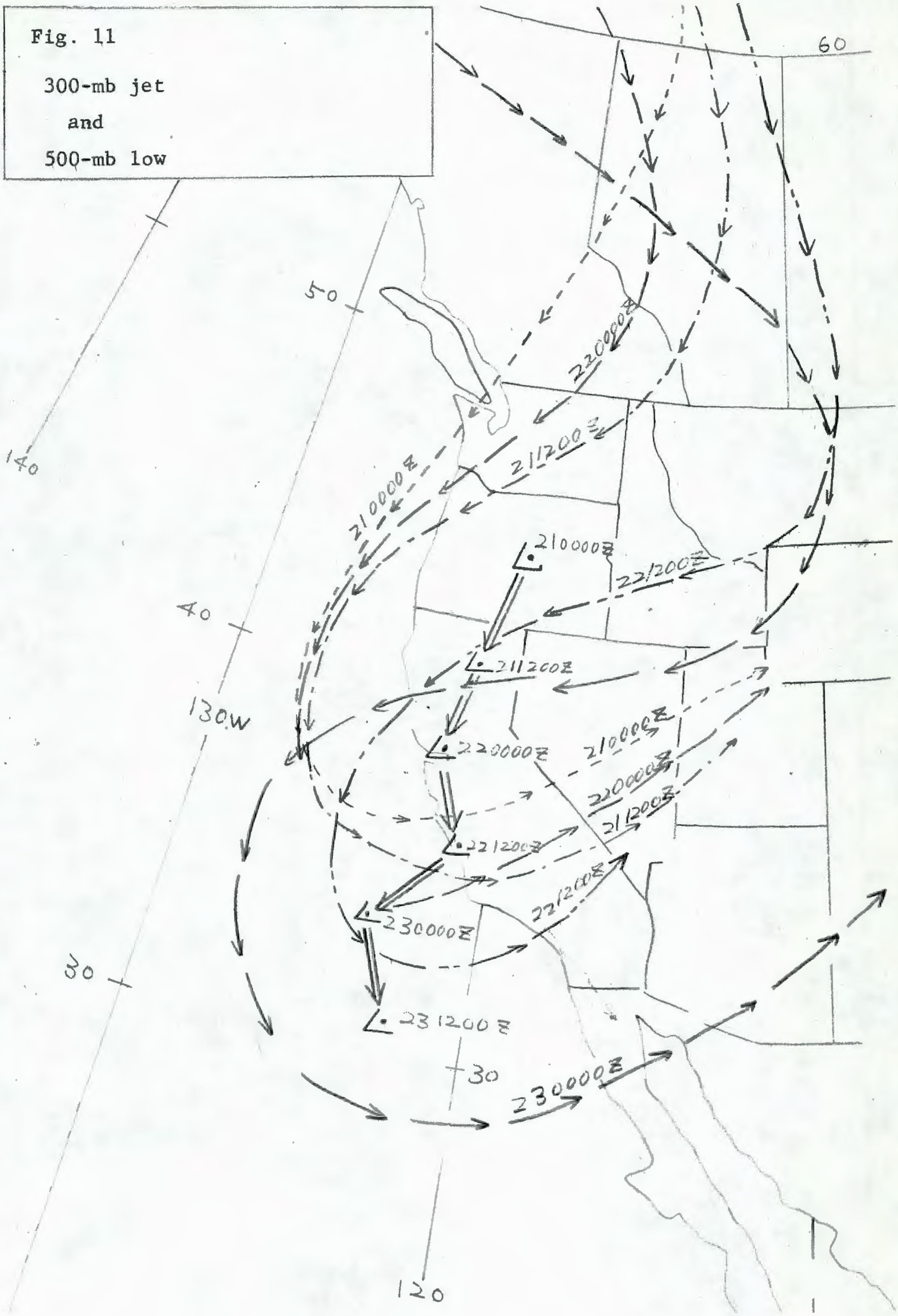
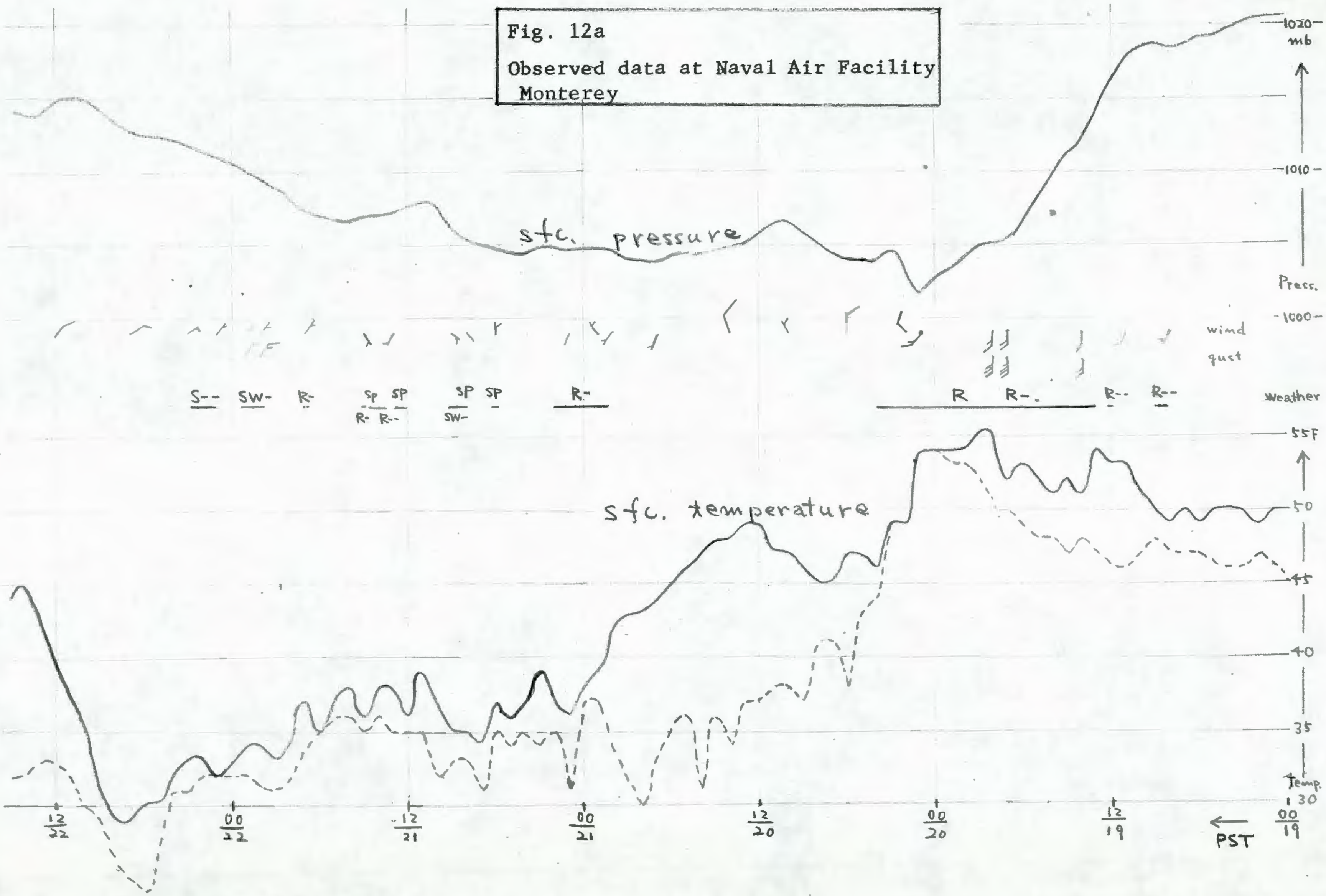


Fig. 12a

Observed data at Naval Air Facility Monterey



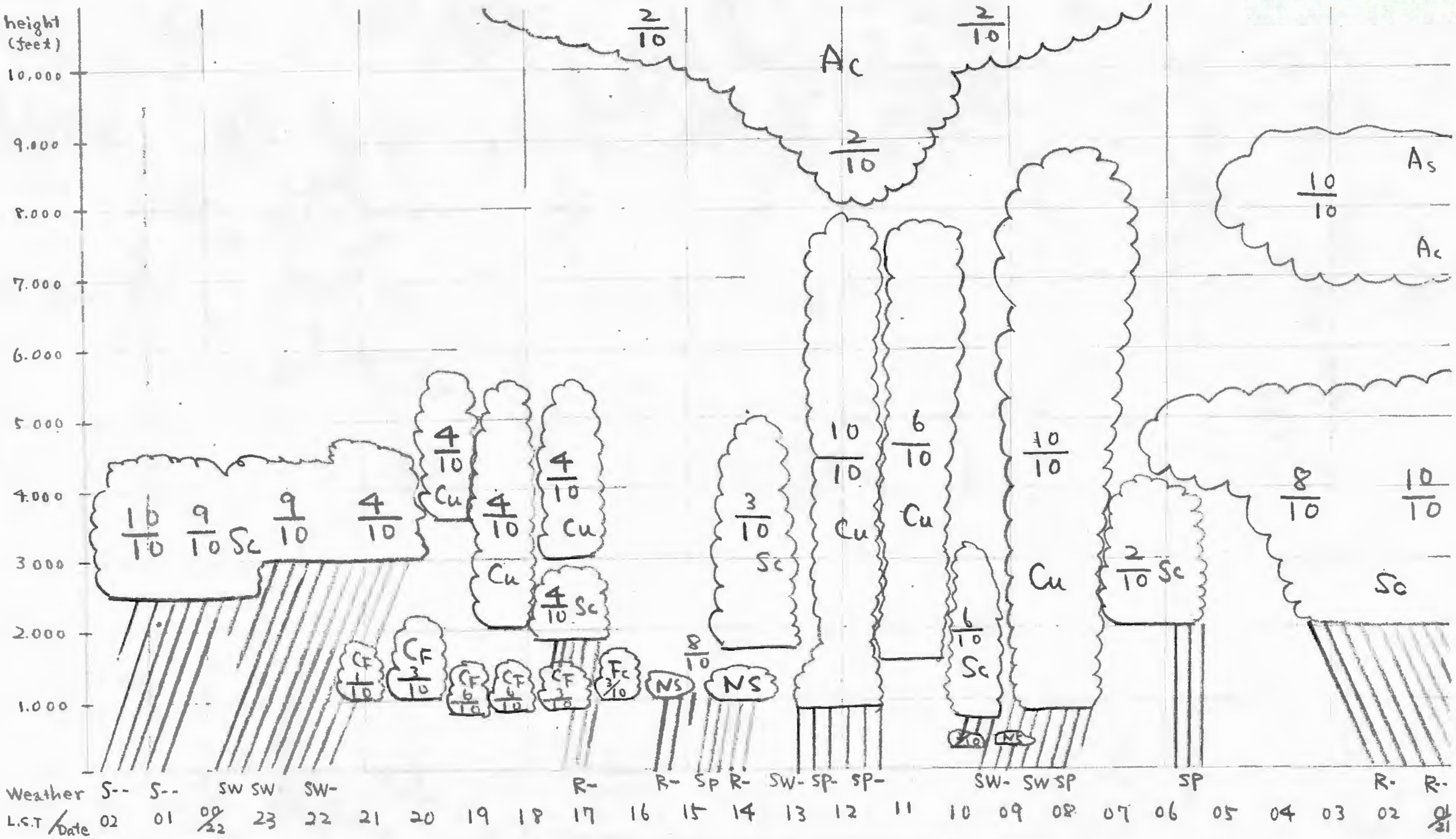


Fig. 12b

Time-height cross section during the snow storm at Naval Air Facility, Monterey.

as shown in fig. 12. Cumulus clouds brought snow pellets and showers (fig. 12b).

The numbers shown at the 850-, 700-, and 500-mb levels in fig. 6b are individual pressure change, $\frac{dp}{dt}$ or ω at these levels. These values (mb/sec) were computed by numerical solution of the ω equation by Clarke and Lawniczak [1].

The 850-mb value is about 3 cm/sec upward, and may be considered as typical of the convectively unstable layer. This upward motion would cause lifting of the layer, with shower-form precipitation. Here, except for a shallow layer near the surface, the temperatures at all levels were less than 0C. Therefore snow pellets or snow showers would be the most probable weather during this period.

In general, the area behind a cold front is one of subsidence associated with anticyclonic flow. However, here there had been significant upward motion associated with cyclonic flow, in particular with the upper-level cold low.

2-7 Movement of the snow area

In fig. 13a, it may be seen that until 200000Z the snow area was restricted to a more or less climatologically snow-favored region; however, after 210000Z it had moved further to the south, especially along the Pacific Coast.

In fig. 13b, c, it may be noticed that the snow over Utah and Arizona was primarily associated with a cold front; however, along the Pacific Coast the situation was different; here the snow may be considered definitely associated with the cold outbreak caused by further S-ward penetration of the cold-core low.

Moreover, it may be said that the first outbreak of cold air associated with the cold front was not cold enough to bring snow along the Pacific coastal low-altitude areas but was cold enough for snow over the

Fig. 13a

The movement of snow area

---- 19th
— — 20th
—·—— 21st
—··—— 22nd

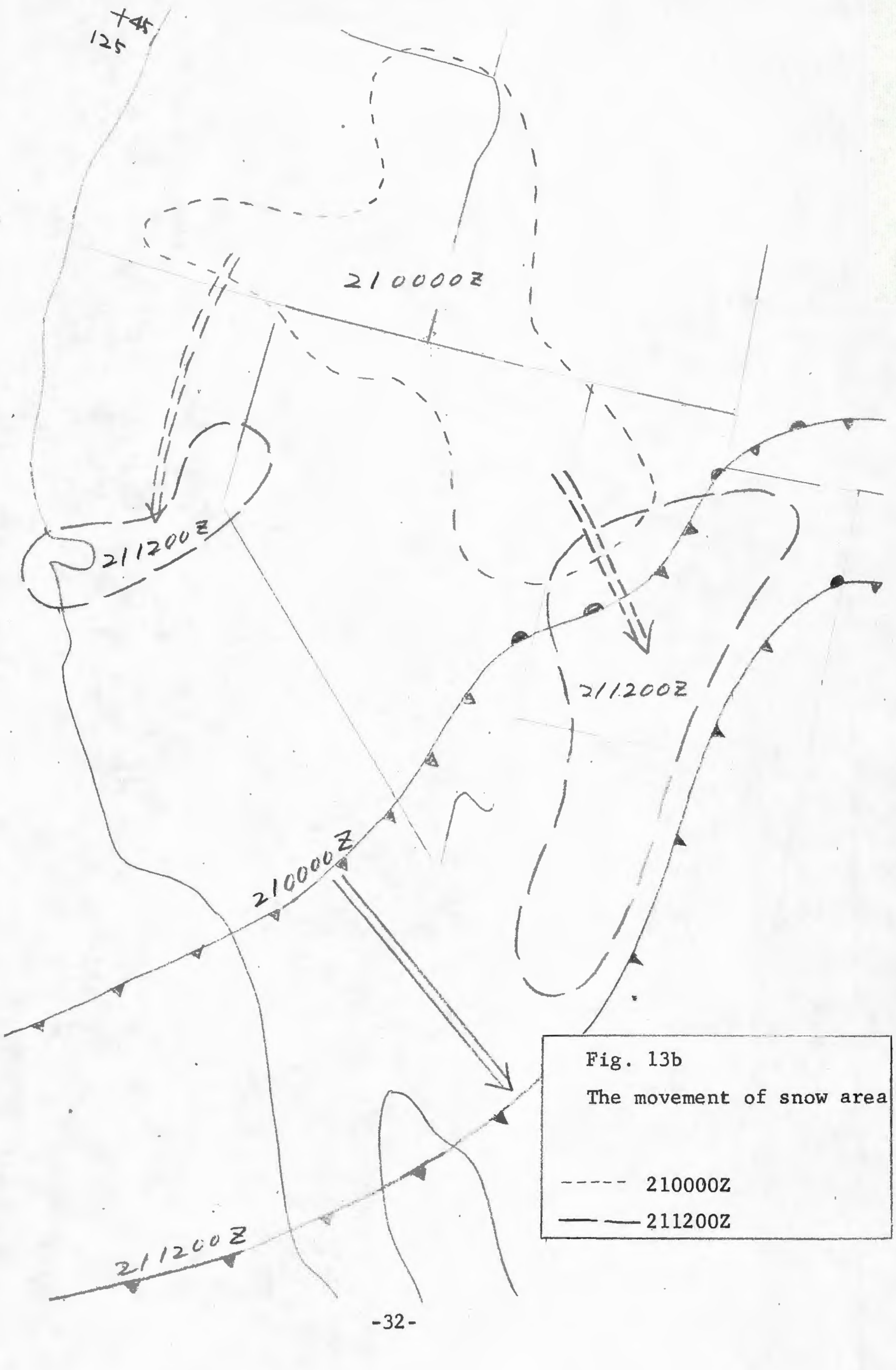
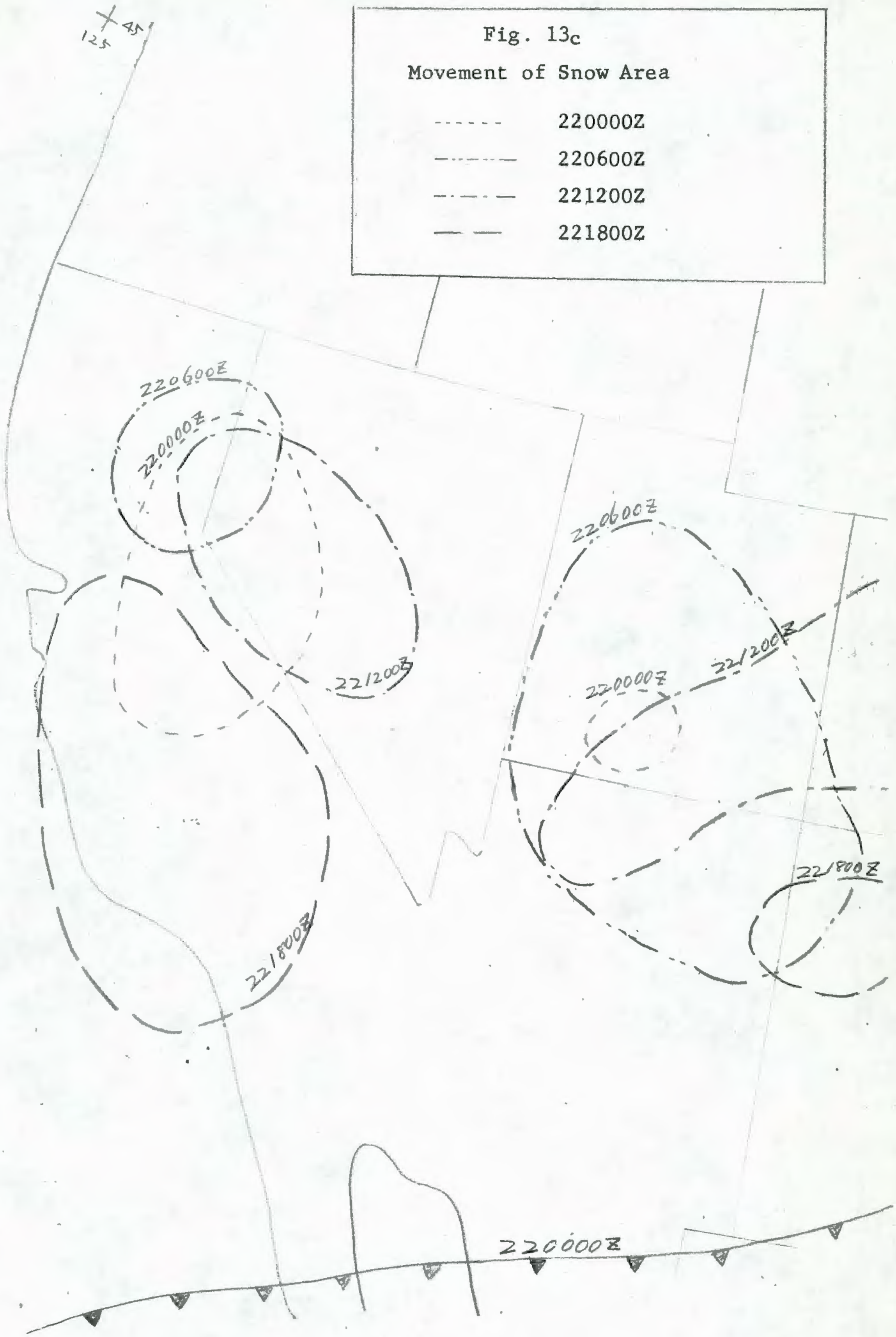


Fig. 13b
The movement of snow area

Fig. 13c

Movement of Snow Area

- - - - - -	220000Z
—··—··—	220600Z
—·—·—	221200Z
— —	221800Z



mountain areas, while the second cold outbreak (associated with the cold-core low) was cold enough for the Pacific Coast.

3. Comparative Study of Monterey Snow

The discussion in the preceding sections concerns only the January 1962 snow. In summary it was seen that this snow was brought by a significant cold outbreak from Canada and this so-called unusual weather was caused by a specific pattern of (1) an Alaskan blocking high, (2) a significant N-S meandering of the jet stream, and (3) an intense cold-core low.

To find if only this synoptic pattern is favorable to snow over Central and Southern California (especially Monterey), several previous snow situations are studied.

3-1 The snow of December 1932

It is recorded in the Monterey Peninsula Herald that on Dec. 11, 1932 the first real snow in recent history fell over Monterey. It had begun shortly after 1200 and consisted of large feathery snow flakes.

In fig. 14, the surface chart for 111300Z Dec. 1932 is shown. Unfortunately upper-level charts were not drawn at that time; however, it may still be seen that: (1) a blocking high was over Alaska; (2) the air trajectory was almost the same as 1962's case; (3) the intense cold outbreak may be considered as caused by the upper cold cyclonic circulation associated with a deep occlusion; and (4) a significant difference as compared to 1962's case is the existence of a warm front moving onto the coast from the Pacific. However, Monterey was on the cold air side of the front during that period. Air temperature was lower by at least 2F than 1962's case.

In summary the type of cold outbreak and air trajectory are similar to 1962's, but an important difference was the snow type, that is, snow

Fig. 14

Surface map at 111300Z December 1932 #

flakes from warm-frontal cloud, not from convective cloud.

3-2 Snow of January 1949

This snow was observed as a trace at Monterey. From fig. 15, the following may be seen: (1) the air trajectory was nearly the same, but the source region was further west and the path was further east than in the 1962 case; (2) the intense ridge over Alaska; and (3) the intense cold-core low at 500 mb which was the main instigator of the cold outbreak, but its path was east of the 1962 path.

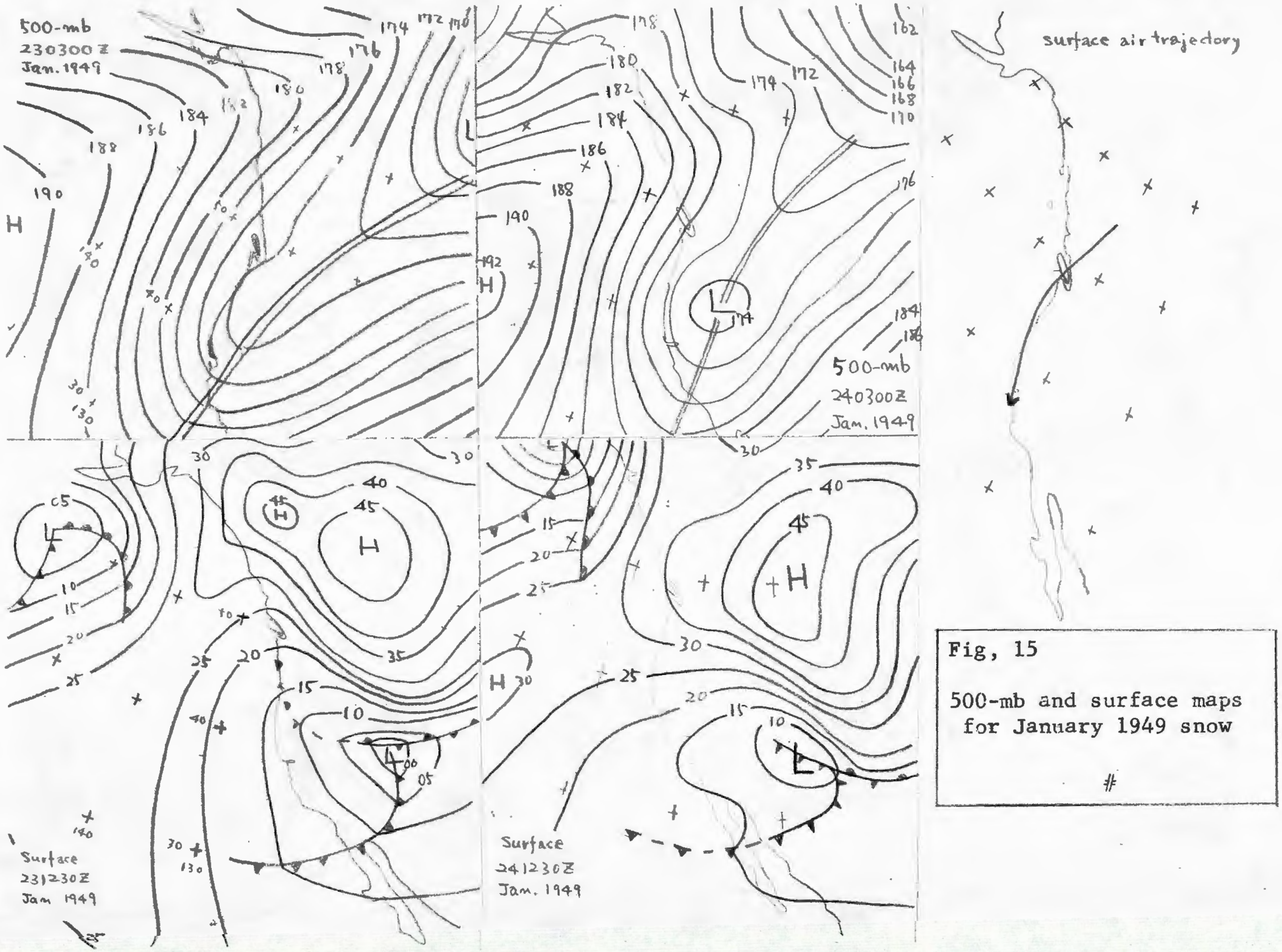
In summary, the mechanism of the cold outbreak was the same, but the air trajectory shows less picking up of moisture on its path over the Pacific and less presumed upward motion over the Monterey area because of the more eastern position of the cold-core low.

3-3 Snow of February and March 1951

This snow was also observed but as a trace at Monterey. As shown in fig. 16, (1) the air trajectory was very similar to 1962's case; (2) the Alaskan ridge was less intense because of the further southern position of its center; (3) there existed a cold-core low which was upper reflection of a surface low, however, when it had reached the vicinity of Monterey it was in the rapid-decay stage; and (4) as in the 1932 case, the snow was at first warm-frontal (in fact it was snow flakes on Feb. 28 and changed to snow pellets on Mar. 1).

3-4 Snow of January 1957

This snow was not observed at N.A.F. Monterey but was seen over the mountains that surround Monterey. Fig. 17 shows that: (1) the Alaskan ridge was very intense; (2) the cold-core low was very intense and its path was very similar to 1962's case; and (3) the air flow, contrary to the other cases, was offshore. Therefore the air was too dry to cause



Fig, 15

500-mb and surface maps for January 1949 snow

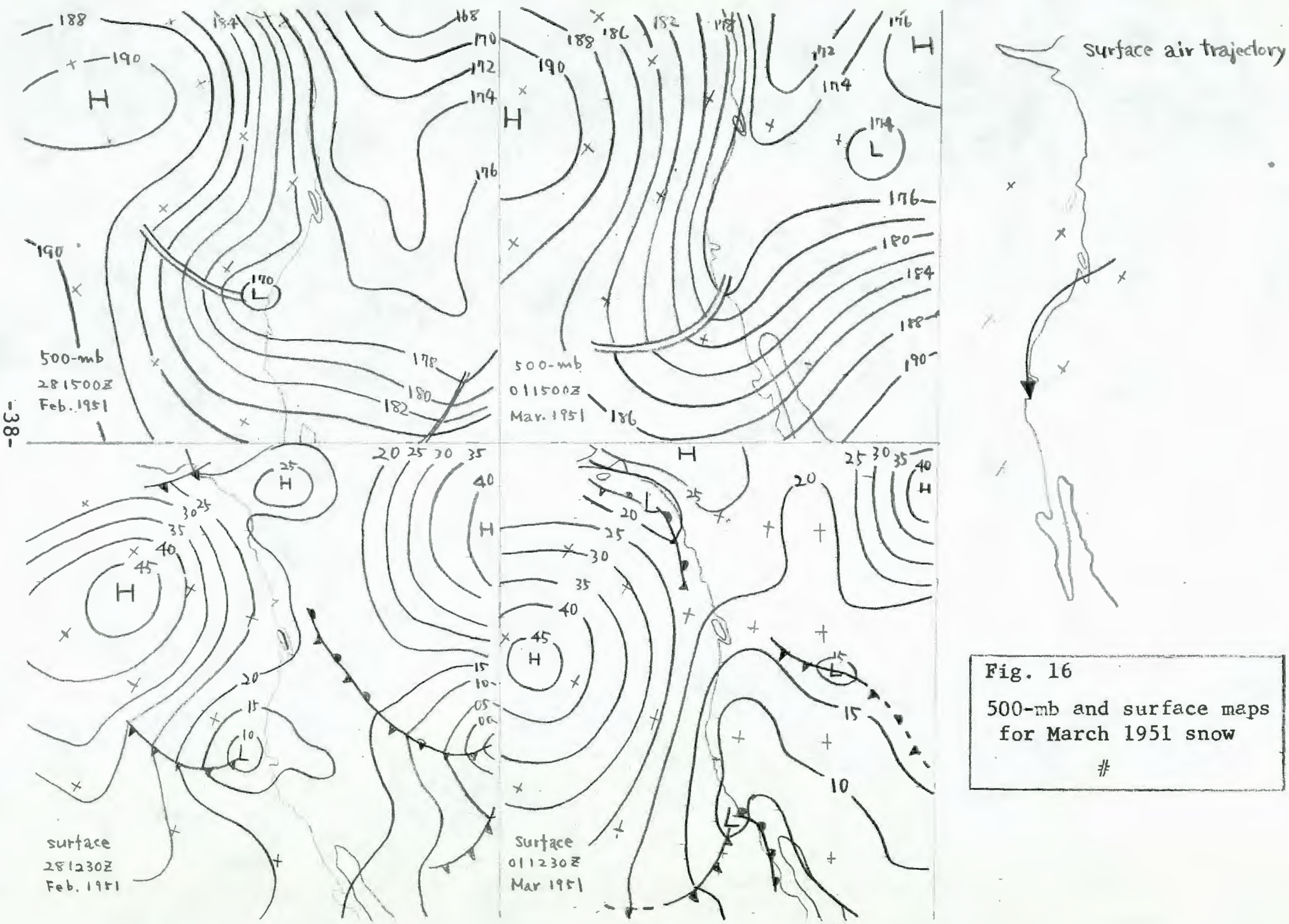


Fig. 16

500-mb and surface maps for March 1951 snow

#

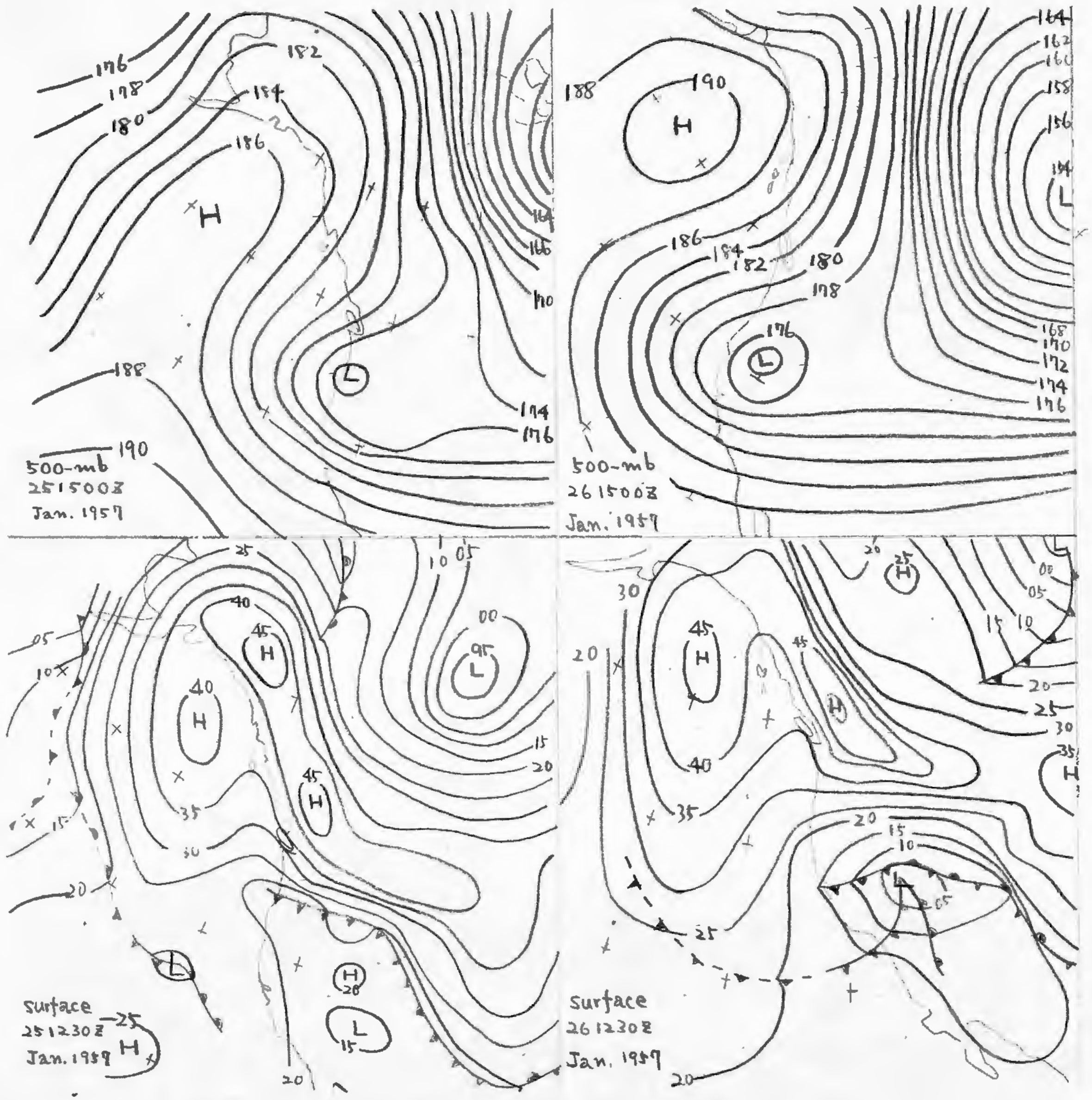


Fig. 17

500-mb and surface maps for January 1957 snow

#

any precipitation except at high elevations. At San Francisco, the dew-point depression was 7F with air temperature 39F at 261230Z and 23F with temperature 39F at 271230Z; this clearly shows that the air had come from inland and was warmed by down-slope motion.

3-5 Summary

As the summary of this section, it may be said that: (1) a nearly stationary intense Alaskan ridge establishes upper-level dynamic instability on its east side and this causes the sharpening of the trough to the east, finally producing a cold-core low; (2) the development and movement of the cold-core low is coincident with the cold outbreak itself, especially in the coastal lowland; and (3) the air trajectory was the critical factor for snow because of picking up of moisture along the path. There will be a certain critical path which is a function of the change in temperature and moisture content effected by the underlying sea-surface properties.

4. The Forecasting Problem

4-1 Temperature and the prediction of snow

The problem of snow prediction may be divided into two steps: (1) forecasting of precipitation; and (2) forecasting of snow against other precipitation forms.

For (1), there are many techniques, including the objective techniques of [4] and [10] for the Monterey area. The latter method (used at N.A.F. Monterey) predicted for this snow-storm period 75°/o chance of precipitation. Therefore, here the problem may be limited to rain vs. snow only.

Step (2) may be further subdivided into (a) thermal conditions, and (b) the influence of the wind which transports the snow.

In order to have snow at ground level, snow particles produced at high altitudes must be carried down without melting. If the temperature is less than 0C in the whole layer to the ground, this condition is easily fulfilled. However, this is not always a necessary condition and the so-called critical temperature must be considered.

According to MacDonald [6] the critical temperature for Albany, Buffalo, New York, and Pittsburgh is 35F, and at 37F the probability of snow will be 20°/o, rain 80°/o; at 32F 80°/o snow, 20°/o rain; and at 30F 90°/o snow, 10°/o rain is the expectation.

Murray [7], on the other hand, found that for England the critical temperature is 34.2F and snow rarely occurs at or above 39F.

According to Nemoto [8], it is 2.5C (36.5F) on the average in Japan. The geographical differences in those critical temperatures may be attributed to the differences in air masses. In England, snow might be brought by mA and mP, in Eastern United States by cP and cA, and in Japan by cP and mP. For Monterey, the air mass which brings snow will be mainly cP (mP is also possible but its temperature must be cold enough to be almost equal to cP.).

Some data for Monterey are given in table 2. Because there are only 6 cases, no definitive criterion is possible; however, in spite of surface temperature variability, the 850-mb temperature seems to have some important effect; that is, as a very crude guide, snow may be expected to begin at or below -5C to -6C.

For problem (b), it is known that the falling speed of snow particles is about 0.5 to 1 m/sec and when the wind speed is 10 m/sec, the angle of snow fall to the horizontal is about 8 degrees [8].

However, this problem is a very complicated one (being affected by convective motion) and it is beyond scope of this study.

Table 2

Temperature and snow at Monterey

Date	Type of snow	Sfc. temperature	850-mb temperature
Dec. 11, 1932	S	30 to 32F	not available
Jan. 24, 1949	not available	30	-6.2C
Feb. 28, 1951	S	35	-4.2
Mar. 1, 1951	SP	41	
Jan. 26, 1957	not available	36	-5.0
Jan. 21, 1962	SP	38 to 35	-6
Jan. 22, 1962	SW	38 to 34	-6
	S	33 to 32	-6
Feb. 24, 1962	SP	44	-4.5

4-2 The actual forecast for January 21-22, 1962

In a preceding section(3-5), large-scale synoptic criteria for snow in California have been given. Those conditions are rather distinct or significant. In general, blocking is a very persistent phenomenon and might have been forecasted effectively by 201200Z at the latest. However, until 201530Z, official forecasts did not give snow over the Central and Southern California Coast but mostly over the Sierra Nevada. The synoptic summaries mentioned that 500-mb blocking over Alaska was continuing, and that the low near the mouth of the Columbia (fig. 2d-200000Z) was moving SE-ward and deepening more than indicated by barotropic methods of forecasting.

The prognostic chart for 500 mb of F.N.W.F. Monterey (barotropic model) also did not show the cut-off low (fig. 18).

It is well known that intense blocking would cause unusual weather anomalies and that a cut-off low would bring colder air than normally accompanies cold advection behind a cold front.

From the above considerations and the fact that rain was forecasted

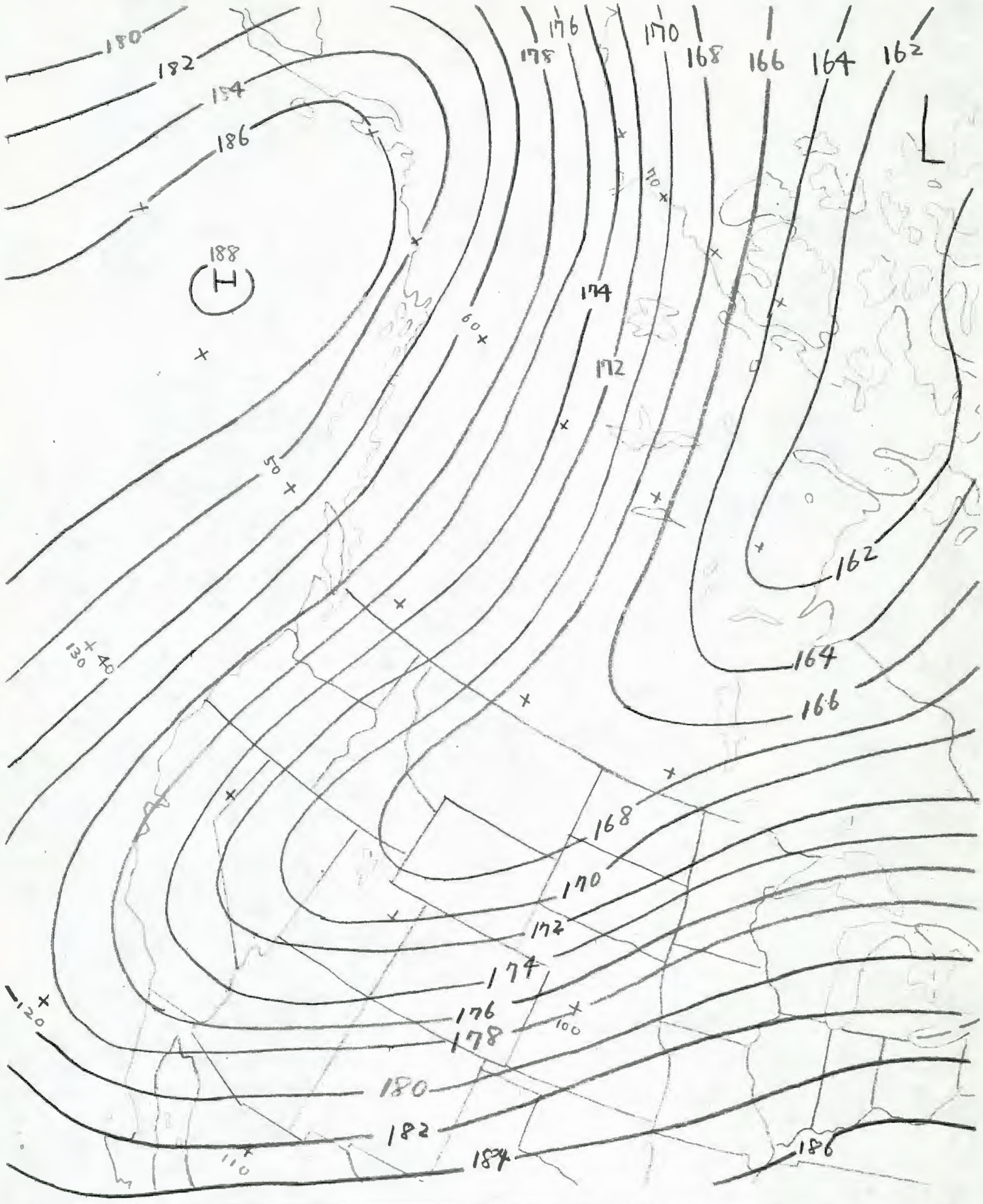


Fig. 18a

24-hr 500-mb prognostic chart for 211200Z by the Fleet Numerical Weather Facility, Monterey.

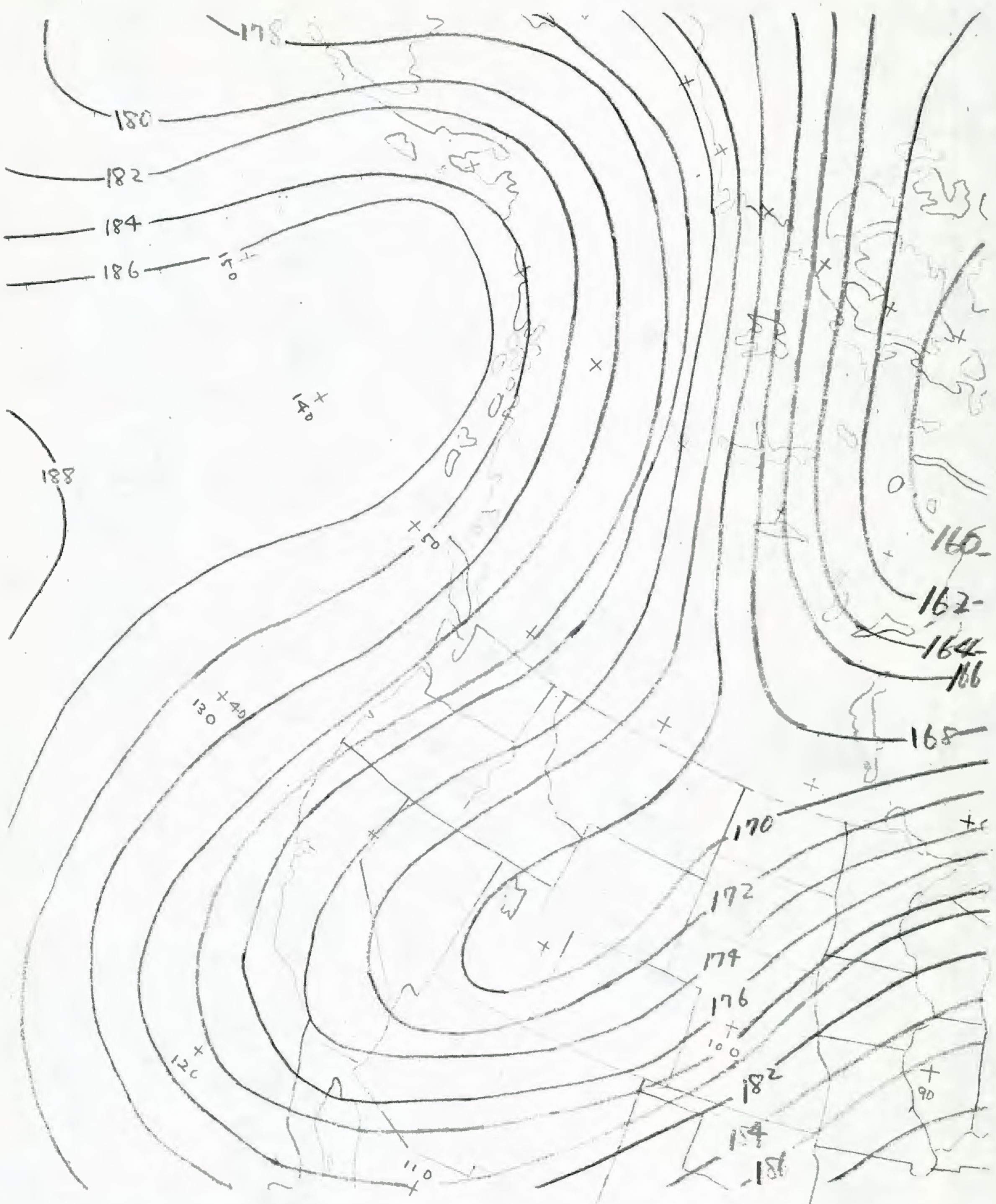


Fig. 18b

24-hr 500-mb prognostic chart for 220000Z by Fleet Numerical Weather Facility, Monterey

rather than snow, the reason for the missed snow forecast may be considered as a result of the failure to forecast the development of the upper cold low.

5. Conclusion

The foregoing study has shown that the snow over the Central and Southern California Coast region was brought by the cP or cA air from Canada having a specific surface trajectory which caused convective instability in its lower layers.

The cold outbreak usually proceeds in two steps; the first step may be considered a weakening of the arctic front by injection of mPk to the south, caused by SE-moving low from the Pacific (C.I.T.Weather Type A [2]); the second step is a fresh outbreak of cPk or cAk which has been forced across the Rocky Mountains by the strong N-S oriented upper flow.

This strong flow has marked anticyclonic curvature in the crest of blocking or [illegible] high over the Alaskan region, and from its dynamic instability, a cutoff low downstream developed.[5, pp. 546], [9, pp. 81].

The cutoff low plays an important role in keeping upper temperatures cold by pronounced upward motion instead of sinking motion generally found behind the cold front.

It seems to be a necessary condition for snow over the Central and Southern California Coast that a N-S oriented strong flow pattern penetrate far to the south, with surface lows moving onto the Oregon-California Coast from the Pacific and SE-ward for a favorable air trajectory.

As a very crude guide for forecasting snow vs. rain at Monterey, an 850-mb temperature of -5 to -6C or lower provides a likely probability of snow.

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